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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04L 1/08, H04B 7/26 — A2

(11) International Publication Number: WO 99/14885

(43) International Publication Date: 25 March 1999 (25.03.99)

(21) International Application Number: PCT/EP98/05908

(22) International Filing Date: 16 September 1998 (16.09.98)

(30) Priority Data:

60/060,707	18 September 1997 (18.09.97)	US
60/088,950	11 June 1998 (11.06.98)	US
09/108,446	1 July 1998 (01.07.98)	US

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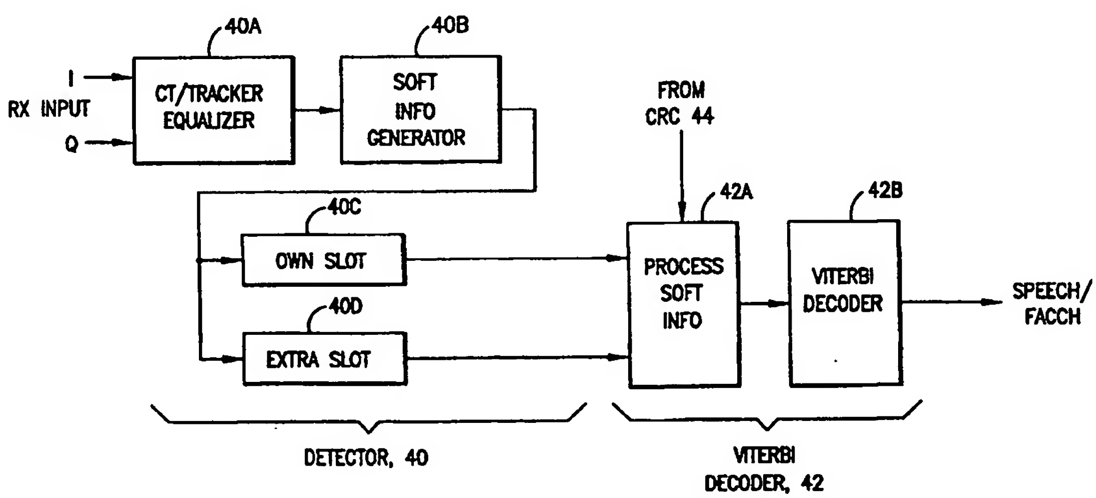
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: TIME DIVERSITY IN A TDMA SYSTEM



(57) Abstract

A TDMA radiotelephone system is described wherein a base station transmits a slot and a repeat of the slot to a mobile station. The mobile station selectively receives the slots, detects soft information from each of the slots, and provides a combination of the soft information to a channel decoder, such as a Viterbi decoder, for enhancing the operation of the channel decoder. In a further aspect of this invention a method is described for operating a wireless communication system includes the steps of: (a) transmitting a time slot and a repeat of the time slot to a channel; (b) receiving the time slot and the repeat of the time slot with a diversity receiver; (c) processing the received time slot and the repeat of the time slot with a first channel estimator and with a second channel estimator, respectively; and (d) performing a joint detection in accordance with a technique that minimizes a metric.

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TIME DIVERSITY IN A TDMA SYSTEM

Priority is herewith claimed under 35 U.S.C. §119(e) from copending Provisional Patent Application Number 60/060,707, filed 9/18/97, entitled "Mobile Station Receiver Performance Improvement by Using Repeated Data Structure in Base Station", by Mika Tuutijärvi and Seppo Alanärä. Priority is also herewith claimed under 35 U.S.C. §119(e) from copending Provisional Patent Application Number 60/088,950, filed 6/11/98, entitled "Time Diversity in TDMA System", by Risto Paatelma, Heikki Berg, and Pekka Kaasila. The disclosures of these Provisional Patent Applications is incorporated by reference herein in their entireties.

This invention relates in general to the field of telecommunications and mobile phones, particularly digital mobile phones that operate in accordance with a Time Division Multiple Access (TDMA) air interface, such as one known as IS-136 and improvements and enhancements thereto. This invention also pertains to the diversity reception and coding of repeated information, and can be applied to all digital TDMA data transmission systems that transmit over a fading channel.

In the U.S. cellular Time Division Multiple Access (TDMA) standard, known as IS-136, both block coding and convolutional coding are used for error detection.

It is well known that Forward Error Coding (FEC) techniques can be implemented to perform either hard-decision or soft-decision decoding, depending on the amount of information conveyed to the decoder with each demodulated symbol. In the simplest implementations, the demodulator makes a definite decision on each received symbol and passes the bits or symbols to a

hard-decision decoder. Hard-decision decoding algorithms are essentially efficient algebraic equation-solving routines, although simple look-up tables are sometimes used for decoding short block codes. Single-error-correcting codes are sometimes implemented with simple shift-register encoders and decoders, the codewords are represented as polynomials, and encoding and decoding are done using polynomial multiplication and division operations.

Soft-decision FEC decoding begins with soft-decision demodulation, in which the demodulator output is quantized to Q levels, where Q is greater than the size of the transmission alphabet. Quantization incurs a loss of information, and thus soft-decision demodulation preserves information that can be profitably utilized with appropriate decoding algorithms. Soft-decision decoding algorithms more nearly resemble signal correlation or matched-filtering operations than equation-solving routines. A number of efficient soft-decision techniques have been devised for decoding block codes. It is known that the soft-decision Viterbi decoding algorithm, widely used for decoding convolutional codes, can also be used to perform optimum soft-decision decoding for some block codes.

In general, soft-decision decoding provides better performance than hard-decision decoding, but at a cost of increased demodulator and decoder complexity. The range of performance improvement achievable will depend to a great extent on the characteristics of the transmission channel. On steady-signal AWGN channels, the theoretical limit on SNR improvement achievable with soft-decision decoding is 3dB. However, practical experience shows that actual improvements of 1-2dB are feasible with algorithms of reasonable complexity, and that larger SNR improvements can be achieved on fading channels.

The foregoing and other problems are by methods and apparatus in accordance with embodiments of this invention.

In a first aspect this invention teaches a method to improve Time Division Multiple Access (TDMA) mobile station receiver Bit Error Rate (BER) and Word Error Rate (WER) performance. The method includes the steps of: (a) receiving a traffic/control channel message having a slotted frame structure; (b) demodulating and then soft-decision decoding a time slot; (c) storing the soft information from the time slot; and (d) subsequently combining by averaging or summing the stored soft information with soft information derived from a subsequently received additional whole or partial time slot.

In a second aspect this invention provides a method for operating a wireless communication system that includes the steps of (a) transmitting a time slot and a repeat of the time slot to a channel; (b) receiving the time slot and the repeat of the time slot with a diversity receiver; (c) processing the received time slot and the repeat of the time slot with a first channel estimator and with a second channel estimator, respectively; and (d) performing a joint detection. The joint detection may be accomplished in accordance with the following:

Minimize metric

$$\Gamma = \sum_{i=1}^{L} k_{i,k} \left| y_{i,k} - c_{i,k} \partial_i \right|^2$$

where Γ is a minimized metric, $k_{i,k}$ is a weight based on the combining algorithm, $y_{i,k}$ is a received sample from diversity branch (slot) i at time k, $c_{i,k}$ is a corresponding channel estimation, ∂_i is a trial symbol for time slot i, and L is equal to the number of repeated slots. The receiver searches for the trial symbol combination which gives the lowest metric.

Other techniques for accomplishing the joint detection and combining the information from more than one time slot may be employed.

The step of transmitting can include the initial step of applying time-time coded modulation to a signal to be transmitted.

According to a third aspect of the present invention, there is provided in a wireless radiotelephone system comprising a base station and a mobile station, a method that includes the steps of:

transmitting a time slot and a repeat of the time slot from the base station to the mobile station;

selectively receiving the time slots, detecting soft information from each of the time slots, and providing a combination of the soft information to a channel decoder; and

performing channel decoding using the combination of soft information.

According to a fourth aspect of the present invention, there is provided a method for improving TDMA mobile station receiver performance, comprising steps of:

receiving a traffic/control channel message having a slotted frame structure;

demodulating and then soft-decision decoding a first time slot;

storing the soft information from the first time slot; and

subsequently using the stored soft information with soft information derived from a subsequently received whole or partial second time slot.

According to a fifth aspect of the present invention, there is provided a wireless radiotelephone system, comprising:

a base station; and

a mobile station;

said base station comprising a transmitter for transmitting a time slot and a repeat of the time slot to the mobile station; and

said mobile station comprising circuitry for selectively receiving the time slots, for detecting soft information from each of the time slots, for providing a combination of the soft information to a channel decoder, and for performing channel decoding using the combination of soft information.

According to a sixth aspect of the present invention, there is provided a method for improving TDMA mobile station receiver performance, comprising steps of:

transmitting, from a base station, a control channel message in a slotted frame structure;

receiving, demodulating and then soft-decision decoding a first time slot in the mobile station;

storing the soft information from the first time slot;

receiving, demodulating and then soft-decision decoding a second time slot wherein the control channel message is repeated;

storing the soft information from the second time slot; and

transmitting a request to the base station for a retransmission of the control channel message if one or both of the stored soft information is below a threshold quality value.

According to a seventh aspect of the present invention, there is provided in a wireless radiotelephone system comprising a base station and a mobile station, a method comprising steps of:

transmitting a time slot and a repeat of the time slot from the base station to the mobile station;

selectively receiving the first and second time slots, detecting soft information from each of the time slots, and providing a combination of the soft information to a channel decoder; and

performing channel decoding using the combination of soft information while periodically retuning a receiver of the mobile station to measure the signal strength of another frequency channel.

According to an eighth aspect of the present invention there is provided a method for operating a wireless communication system, comprising steps of:

transmitting a time slot and a repeat of the time slot to a channel, each of the transmitted time slots being modulated to convey the same information;

receiving the time slot and the repeat of the time slot with a diversity receiver;

demodulating and then processing the received time slot and the repeat of the time slot with a first channel estimator and with a second channel estimator, respectively; and

performing a joint detection on the received time slot and the repeat of the time slot so as to determine the information.

According to a further aspect of the present invention, there is provided a wireless communication system, comprising:

a base station comprising a transmitter for transmitting a time slot and a repeat of the time slot to a channel; and

a mobile station comprising a diversity receiver for receiving the time slot and the repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot, said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for determining the information.

According to a further aspect of the present invention, there is provided a wireless communication system, comprising:

a base station comprising a transmitter for transmitting information in a time slot and a repeat of the time slot, said base station comprising an 8PSK modulator and means for time-time coding the information, wherein each time slot contains 162 symbols and has 130 data symbols; and

a radiotelephone comprising a receiver for receiving the time slot and the repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot, said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for extracting the information.

According to a further aspect of the present invention, there is provided in a wireless radiotelephone system comprising a base station and a mobile station, a method that includes the steps of:

transmitting a time slot and, at a subsequent time, at least one repeat of the time slot from the base station to the mobile station;

receiving the time slots; and

determining information transmitted to the mobile station by combining the time slot and the at least one repeat of the time slot.

According to a further aspect of the present invention, there is provided a mobile station for use in a Time Division Multiple Access (TDMA) communication system, wherein the mobile station comprises circuitry for selectively receiving a time slot and a repeat of the time slot, for detecting soft information from each of the time slots, for providing a combination of the soft information to a channel decoder, and for performing channel decoding using the combination of soft information.

According to a further aspect of the present invention, there is provided a mobile station for use in a Time Division Multiple Access (TDMA) communication system, wherein the mobile station comprises a diversity receiver for receiving a time slot and a repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot; said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for determining the information contained therein.

According to a further aspect of the present invention, there is provided a base station for use in a Time Division Multiple Access (TDMA) communication

system, wherein the base station comprises means for automatically transmitting a repeat of a time slot on an adjacent vacant time slot.

It is a first advantage of this invention to provide an expanded use of diversity for improving the operation of a wireless telecommunications system.

It is another advantage of this invention to provide a diversity gain that is achieved by repeating a previous time slot,-if it is not used by other user, in combination with an algorithm that combines soft decision outputs that are detected independently from both repeated slots.

It is another advantage of this invention to provide a technique that expands and extends the use of diversity in a TDMA mobile station, such as a cellular telephone, personal communicator, or wireless telephone.

It is another advantage of this invention to provide an improved method for decoding data in a mobile station that is connected to a base station through an RF link.

It is a further advantage of this invention to provide a base station that transmits a slot and a repeat of the slot to a mobile station.

It is a further advantage of this invention to provide a base station that transmits a slot and a repeat of the slot to a mobile station, and to further provide a mobile station that selectively receives the slots, detects soft information from each of the slots, and provides a combination of the soft information to a channel decoder, such as a Viterbi decoder, for enhancing the operation of the channel decoder.

It is a further advantage of this invention to provide an expanded use of diversity that employs different coding in repeated slots, and/or repetition performed for all available slots, and/or repetition performed with delay.

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention, when read in conjunction with the attached Drawings, wherein:

Fig. 1 is a block diagram of a mobile station that is constructed and operated in accordance with this invention;

Fig. 2 is an elevational view of the mobile station shown in Fig. 1, and which further illustrates a wireless communication system to which the mobile station is bidirectionally coupled through wireless RF links;

Figs. 3A and 3B are block diagrams that illustrate in greater detail various portions of the mobile station controller shown in Fig. 1;

Figs. 4A-4G illustrate various timing and slot format examples that are useful in gaining an understanding of this invention;

Fig. 5 is a slot timing diagram that is useful in understanding a MAHO aspect of this invention;

Fig. 6A is a block diagram of a portion of the base station shown in Fig. 2;

Fig. 6B illustrates a slot format implemented by the base station components shown in Fig. 6A;

Fig. 7 is a block diagram of a simplified IS-136 simulation model that is useful in explaining the teachings of a further aspect of this invention;

Fig. 8 illustrates an embodiment of a receiver in accordance with the further aspect of this invention;

Fig. 9 is a constellation diagram of an 8PSK modulated signal wherein gray coding is employed;

Fig. 10 depicts a simple repetition code, wherein a symbol 0 is mapped to symbol 0 of slot 1 and to symbol 0 of slot 2, symbol 1 is mapped to symbol 1 of slot 1 and to symbol 1 to slot 2, etc.;

Fig. 11 depicts a time-time (TT) code in accordance with an embodiment of this invention, wherein symbol 0 is mapped to symbol 0 of slot 1 and to symbol 0 of slot 2, symbol 1 is mapped to symbol 1 of slot 1 and symbol 5 is mapped to slot 2, etc.;

Figs. 12A-12F are graphs showing simulation results of a time diversity embodiment of this invention, wherein in the simulations of Figs. 12A, 12B, 12C the repetition code of Fig. 10 was used, while in the simulations of Figs. 12D, 12E, 12F the time-time (TT) code of Fig. 11 was used;

Fig. 13 is a graph illustrating the diversity gain obtained from slot repetition at a BER of 1%, and where a 3dB energy gain can be added to the diversity gain values;

Fig. 14 depicts a forward time slot for a proposed enhanced version of IS-136 (TIA IS-136, Rev. C);

Fig. 15 depicts eight phase rotations that a transmitted symbol may assume when using 8PSK modulation;

Fig. 16 is block diagram showing N TT-code modulators and associated interleavers for providing an original time slot and N-1 repeats of the original time slot;

Fig. 17 is a logic flow diagram showing one method for providing power saving by using independent slot detection; and

Fig. 18 is a logic flow diagram showing a second method for providing power saving by using a combination of information received from a plurality of time slots.

Reference is first made to Figs. 1 and 2 for illustrating a wireless user terminal or mobile station 10, such as but not limited to a cellular radiotelephone or a personal communicator, that is suitable for practicing the various aspects of this invention. The mobile station 10 includes an antenna 12 for transmitting signals to and for receiving signals from an antenna 31 of a base site or base station 30. The base station 30 is typically a part of a cellular network comprising a Base Station/Mobile Switching Center/Interworking function (BMI) 32 that includes a mobile switching center (MSC) 34. The MSC 34 provides a connection to landline trunks, such as the Public Switch Telephone Network (PSTN), when the mobile station 10 is involved in a call.

The mobile station includes a modulator (MOD) 14A, a transmitter 14, a receiver 16, a demodulator (DEMOD) 16A, and a controller 18 that provides signals to and receives signals from the transmitter 14 and receiver 16, respectively. These signals include signalling information in accordance with the air interface standard of the applicable cellular system, and also user speech and/or user generated data. The air interface standard is assumed for this invention to include a physical and logical frame structure, although the teaching of this invention is not intended to be limited only to this type of frame structure, or for use only with a TDMA or an IS-136 or similar compatible mobile station.

It is understood that the controller 18 also includes the circuitry required for implementing the audio and logic functions of the mobile station 10. By example, the controller 18 may be comprised of a digital signal processor (DSP)

device, a microprocessor device, and various analog to digital converters, digital to analog converters, and other support circuits. The control and signal processing functions of the mobile station 10 are allocated between these devices according to their respective capabilities.

A user interface includes a conventional earphone or speaker 17, a conventional microphone 19, a display 20, and a user input device, typically a keypad 22, all of which are coupled to the controller 18. The keypad 22 includes the conventional numeric (0-9) and related keys (#,*) 22a, and other keys 22b used for operating the mobile station 10. These other keys 22b may include, by example, a SEND key, various menu scrolling and soft keys, and a PWR key. The mobile station 10 also includes a battery 26 for powering the various circuits that are required to operate the mobile station.

The mobile station 10 also includes various memories, shown collectively as the memory 24, wherein are stored a plurality of constants and variables that are used by the controller 18 during the operation of the mobile station. For example, the memory 24 stores the values of various cellular system parameters and the number assignment module (NAM). An operating program for controlling the operation of controller 18 is also stored in the memory 24 (typically in a ROM device).

It should be understood that the mobile station 10 can be a vehicle mounted or a handheld device. It should further be appreciated that the mobile station 10 can be capable of operating with one or more air interface standards, modulation types, and access types. By example, the mobile station may be capable of operating with any of a number of other standards besides IS-136, such as GSM. It should thus be clear that the teaching of this invention is not to be construed to be limited to any one particular type of mobile station or air interface standard.

Fig. 3A illustrates a portion of the receiver, which comprises an RF section (blocks 16 and 16A of Fig. 1) and a DSP section 18A which forms a part of the controller 18 of Fig. 1. In this embodiment of the invention the received time slots can be modulated with $\Pi/4$-shift DQPSK modulation, and are then demodulated. The demodulated In-phase (I) and Quadrature (Q) signals are fed into the DSP section 18A for decoding. A detector block 40 of the DSP section 18A is often referred to as an equalizer or carrier tracker (CT). Soft decisions (referred to herein also as soft info or soft infos) for the received bits of a slot are generated in the detector block 40 and are fed to a Viterbi channel decoder 42 for further analysis. Later in the receiver chain there is found a Cyclic Redundancy Check (CRC) block 44 that performs error checking, followed by a speech decoder block 46 that formulates a speech signal that is eventually converted to an analog speech signal and output from the earpiece or speaker 17. The operation of Viterbi decoders, CRC checkers, and various types of speech decoders are known in the art.

This invention relates most particularly to utilizing the soft infos in the manner shown in Fig. 3B. Fig. 3B shows that the detector 40 includes a carrier tracker equalizer 40A, a soft info generator 40B, and a pair of registers 40C and 40D. Register 40C is referred to as an "own slot" register, while register 40D is referred to as an "extra slot" register. The Viterbi decoder 42 is shown to include soft info processing block 42A, followed by the Viterbi decoder block 42B.

After generating the soft infos of a slot in the detector 40 the soft infos are saved in the own slot register 40C. When receiving a repeated slot, the soft infos of the repeated slot are saved in the extra register 40D and then summed or averaged with the soft infos of the previously received slot, having the same contents, in the soft info processing block 42A. This is done to improve the quality of the soft-decision information that is input to the Viterbi decoder block 42B.

In the example of Fig. 3B the registers 40C and 40D for the first transmitted slot and the repetition of the first slot, respectively, are shown as being located in the detector block 40. However, these registers could as well be located within the Viterbi decoder block 42.

It should also be noted that it is possible that the repeated slot summing/averaging is not used in every case. For example, if the CRC check of the first-transmitted slot is passed, indicating no errors, the repeated slot may not be received and processed. In this case the mobile station 10 can be set into a power save mode, or at least the combining of the soft infos from registers 40C and 40D can be eliminated, thereby saving power. That is, the mobile station can be placed in a reduced power state of operation at least during a time that the second time slot would be received and/or processed. The control feedback from the CRC checker 44 is generally shown as the error/no error line that is connected back to the Viterbi decoder block 42, and/or to the power save controller (not shown).

In general, the teaching of this aspect of the invention can be utilized in at least two different situations. In a first situation the mobile station 10 is receiving data/speech from a traffic channel, while in a second situation the mobile station 10 is receiving control messages from a control channel or from the traffic channel.

In the traffic channel of the U.S. TDMA system there are three downlink slots (at full rate) in the same RF channel, allowing three separate traffic channels (users) in the same frequency channel. Reference in this regard can be had to the slot structure of Fig. 5.

In accordance with an aspect of this invention, if there is free capacity in the base station 30 such that there are unused slots available, the base station 30 can order the mobile station 10 to a channel where there are at least two consecutive time slots available. If, for example, slots 2 and 3 are unused (see

Figs. 5, 6A and 6B), the base station 30 commands the mobile station 10 to slot 2 and begins to transmit data to the mobile station 10 in both slots 2 and 3, wherein the data in slot 3 is a repetition of the data in slot 2. The base station 30 also informs the mobile station 10 to as well receive and use the data in slot 3 (if required). If a need arises to place a new user into slot 3 (such as at peak traffic periods), the base station 30 informs the mobile station 10 that the data in slot 3 is no longer available, and the mobile station 10 reverts to a conventional slot reception technique.

In Fig. 6A the base station 30 can be seen to include a plurality of speech/FACCH data generators 30A-30C (preferably implemented by software), one for each of three users, a block 30D for combining the slot outputs of the data generators into a TDMA frame, and an RF section 30E connected to the antenna 31. In this example the data generator 30B for user 2 is shown to be disconnected by the switch SW. In this case slots 1 and 2 are both used to transmit the Data A corresponding to user 1, thereby repeating in slot 2 the slot data from slot 1 as shown in Fig. 6B.

It is within the scope of the teaching of this invention for the mobile station 10 to autonomously determine that a new user has been placed in a slot previously used to repeat the mobile station's data transmission. For example, if the mobile station 10 is receiving its own slot and the additional slot in slots 2 and 3, respectively, and if the correctly decoded data is found to be the same in both slots 2 and 3, the mobile station 10 is assured that slot 3 is a repeat of slot 2. However, if both slots are correctly decoded, but the data is found to not be equal, then the mobile station 10 can make a decision that the data in slot 3 is intended for another user and then terminate the reception of slot 3.

A further aspect of this invention is the correct handling by the mobile station 10 of Mobile Assisted Handoff (MAHO) measurements, which are typically performed during the idle time between RX and TX slots (see Figs. 4A-4E and 5). The mobile station 10 performs MAHO measurements after receiving its

own slot before the beginning of the transmit slot (about 5 ms later) as indicated in Fig. 4A. Taking into account the settling times of the mobile station frequency synthesizer it may be impractical to receive all of the data in the additional, repeated slot (slot 3 in example of Fig. 5) without making significant changes in the mobile station 10 operation.

To overcome this problem it is possible to modify the operation of the mobile station 10 such that it samples the receive channel at the same time as it transmits the data (TX-slot) on another frequency, and the MAHO channel reception is postponed until later (e.g., after the TX slot or next frame, see Fig. 4B).

It can also be decided that the additional slot is received only in the case when DTX (Discontinuous Transmission) is active, which means that the TX slot is not used for transmission, and MAHO sampling can be done after the extra slot is received (see Fig. 4C).

Combining the use of this invention with DTX operation provides the best overall results, and is thus the preferred embodiment, since the next, repeated slot can be fully received without detriment to the MAHO operation.

It is also within the scope of this invention to receive only part of the data in the additional slot (e.g., up to about 5 ms of data in the U.S. TDMA system), and the MAHO sampling is then performed after the TX slot (see Fig. 4D). The performance of MAHO measurements is not a problem in the GSM system, since the GSM slot length is specified to be only about 1/8 of the frame duration (Fig. 4E), and the extra slot can be received during the IDLE time (6/8 of the frame - MAHO sampling time). It should again be noted that the reception of the extra slot can be used only when needed. Exemplary criteria for activating the reception of the extra slot in the mobile station 10 can be one or more of the Bit Error Rate (BER), the Word Error Rate (WER), or a CRC failure in the primary slot (e.g., slot 2) data.

The extra slot data can be processed as described in Figs. 4F and 4G. In the Fig. 4F example the symbols (bits) are selected by bit detection from the slot which gives the better signal quality for the entire slot, or for the separate bits in the detector 40. In Fig. 4G the average (sum) of the soft infos of the two slots is calculated for each symbol (bit). It is also possible to select the data (slot) which gives the correct data CRC and/or lower BER of the two received slots.

Discussing Figs. 4A-4G now in greater detail, Fig. 4A shows the normal timing of the mobile station 10 in slot 2 on a digital traffic channel in the U.S. TDMA system. The RX slot, MAHO slot, and TX slot are physically in different frequencies. Fig. 4B shows that RX and TX can be active at the same time. The MAHO sampling (M) of the first measurement is done immediately after the TX slot, if the synthesizer can be settled to the MAHO frequency and then back to the RX slot in 1.8 ms. An alternative for MAHO sampling is executed only (in normal timing) in case there is no need for the following slot reception (BER-0%). Fig. 4C shows the case where the TXC is inactive at the second TX slot time (indicated by the arrow), such that the following slot (slot 3) can be received. In this case the MAHO sampling can be executed before the next primary RX slot reception. Fig. 4D shows the case where only a part of the following slot (3) is sampled and used in the decoding process. This timing diagram requires that synthesizers are settled on both TX and RX frequencies at the same time, but does not require simultaneous RX and TX functionality. The MAHO sampling requires a fast synthesizer settling time, unless the MAHO sampling can be performed only during time intervals when slot 3 is not required. Fig. 4E shows a timing diagram for the case when the slot length is small (e.g., 1/7) compared to the frame length (similar to the GSM case which has the 1/8 slot/frame structure). Additional repetitive data in slot 3 can be received if there is not enough time for both TX and MAHO.

Fig. 4F shows the case where best quality indications are selected for each bit from both received slots. If only a few soft infos in the second slot (slot 3) are

available, the other slot data can be selected for the decoding process. The Viterbi decoder 42 can also select the better decoding result, i.e., which one yields the better BER of the two quality buffers 40C and 40D (assuming that decoding is successful from both slots).

Finally, Fig. 4G illustrates sample selection for the decoder 42 in a sample by sample case by adding sample qualities from both slots. A negative value represents bit 1 quality and a positive value represents bit 0 quality. The larger (positive or negative) the value the more secure the decision. The channel decoder (e.g., the Viterbi decoder 42) can readily correct the remaining (possible) errors which have relatively small (absolute) quality values (insecure decision by the detector 40). The channel decoder can also decode the received data word from (both) separate slot qualities to ensure that the data received in slots 2 and 3 are identical. If the decoding process succeeds from slot 2 without any bit errors, decoding using the other slot qualities can be discarded for power saving purposes.

In general, the performance of the Viterbi decoder 42 is improved when the detector 40 provides better (more reliable) quality values for the Viterbi calculations. For the case where the CRC check of both slots gives the correct result (after Viterbi decoding, see Fig. 3A), but the data is different in these two slots, the mobile station 10 can determine that the additional slot data is destined for another user, as was discussed above. Such a check may be desirable for security and other reasons.

Advantages provided by this aspect of the invention include a compatibility with the existing U.S. TDMA (IS-136) specification, a more flexible implementation, no requirement to perform significant channel decoding changes, and no mobile station 10 or base station 30 hardware design changes. Also, there is no significant additional signalling penalty to switch this function OFF/ON, as the use of this invention can be easily controlled by the mobile station 10 (if not needed) in good signal conditions (power save) or in the DTX low state.

The use of this aspect of the invention can also be employed when receiving certain control messages that already are repeated according to the current specification. Examples include the Fast Associated Control Channel, or FACCH, which is sent on the traffic channel, or page messages of the control channel. For the case of control channel page messages the primary superframe contents are repeated in the secondary superframe. If the mobile station 10 is unable to decode both the first-sent slot and the repeated slot, it may sum/average the soft infos of the two slots in order to improve the page message reception. A similar method is applicable also in the GSM system. The improvement in reception in the control channel can be significant since the control channels are more sensitive to fading because of the use of intra-frame interleaving and the use of only 1/2 rate convolutional coding.

For the case of the traffic channel the control messages that could benefit form this method are FACCH messages as described in IS-136.2, in Table 3.7.3.1.3.2-1. It is also within the scope of this invention not to repeat FACCH frames, as specified in the current specification, but rather to create and send an Error Acknowledge message from the mobile station 10 to the base station 30 if the soft infos of the already received frames do not meet some predetermined reliability threshold. In this case the base station 30 may retransmit only the message or messages identified in the Error Acknowledge message.

It is also possible to utilize the method of this aspect of the invention in data transmission (both circuit switched and packet data) as described in the IS-130.1 Radio Link Protocol.

Furthermore, it should be realized that more than one repeated slot can be used, with a corresponding increase in the number of storage registers.

Having thus described the first aspect of this invention, the second aspect of this invention will now be described with reference to Figs. 7-15.

By way of introduction, it should first be noted that there exists in the literature a number of different coding schemes. One efficient scheme is a combination of coding and modulation, such as trellis or block coded modulation.

An extension to this technique is space-time coded modulation (STCM), wherein a simplest conventional STCM-system has two transmitter antennas (in the base station), both transmitting at the same time and frequency. Each diversity branch has its own modulation code. When the modulation codes are properly selected significant gains are achieved, as compared to the case when both antennas transmit with exactly the same modulation code. The number of transmit diversity branches may be unlimited.

This technique can be extended for use in repeated slots, where two time slots contain the same information but different coding, i.e. Time-Time Coded Modulation (TTCM). When slot repetition is employed the use of a different modulation code between the slots does not result in any bandwidth reduction. TT-coding may be considered as a combination of coding and then interleaving into two slots.

It is expected that in the future mobile stations will be able to transmit and receive at the same time (multi-slot receivers). As such, more than one slot repetition can be employed, and the number of diversity branches may thus be more than two.

It is known that diversity gain is sensitive to the correlation of the amplitude of the diversity branches. In a slow fading situation the achieved gain is low, as will be seen below, if two consecutive slots are repeated. This is due to the high correlation that exists between the two consecutive slots. In a data transmission application the delay is not typically a limiting factor, and the correlation can be

greatly reduced by using a longer delay between slots. The tradeoff is the larger memory requirement of the receiver. For a speech application a delay longer than one TDMA frame or block is generally not practical.

To facilitate an understanding of this aspect of the invention the use of one repeated slot will be assumed, first without any coding difference and then with TTCM used as an example.

In the above-described aspect of this invention a post-detection combining algorithm was considered. However, repeated slots can be detected with any diversity algorithm. Diversity gain can be achieved if any information is used from the repeated slot(s).

A conventional classification of diversity receiver algorithms breaks down into combining algorithms and selection algorithms.

In the combining algorithms the decision is based on a combination of each diversity branch, and the branches can be weighted differently according to some criteria (e.g., signal strength, signal quality). Simulation results of one specific combining algorithm are described below, and this is assumed to be the most efficient as well as the most practical implementation.

In the selection algorithms one diversity branch is selected over the other(s) according to some criteria. In some cases even a random selection of one of the diversity branches can yield diversity gain. The selection between diversity branches can be done, for example, on a slot by slot, or symbol by symbol, or even a bit by bit basis.

Although many different diversity algorithms can be used in conjunction with the detection of repeated slots, the following description will be made in the context of only the combining algorithm. However, those skilled in the art will realize that other algorithms can be used as well.

Also, only a flat fading channel is considered below. However, the receiver structure (Fig. 8) can be readily expanded to frequency selective channels (equalizer).

One suitable algorithm is described as follows:

Minimize metric·

$$\Gamma = \sum_{i=1}^{L} k_{i,k} \left| y_{i,k} - c_{i,k} \partial_i \right|^2$$

where Γ is a minimized metric, $k_{i,k}$ is a weight based on the combining algorithm, $y_{i,k}$ is a received sample from diversity branch (slot) i at time k, $c_{i,k}$ is a corresponding channel estimation, ∂_i is a trial symbol for time slot i, and L is equal to the number of repeated slots. The receiver searches for the trial symbol combination which gives the lowest metric.

In other embodiments of this invention other algorithms can be used for combining information from more than one time slot, and the teachings of this invention are not to be construed to be limited to the use of only the foregoing algorithm.

Further in this regard, and referring to Fig. 15, in coherent 8PSK modulation a transmitted symbol can have one of eight possible phase rotations. In the foregoing equation the error distance for each of these possible symbols is estimated. The algorithm is thus as follows:

1. Measure the distance of symbol 0 as transmitted

2. Measure the distance of symbol 1 as transmitted

8. Measure the distance of symbol 7 as transmitted

In this algorithm, and referring to line (1.) and to Fig. 15, the trial symbol was symbol 0 = →; in the second line (2.) the trial symbol was symbol 1 = ↗; etc.

Diversity receivers can be used in a manner described above for the first aspect of this invention. First a received slot is detected, and if it contains an allowed code word, reception is accepted. Else, the repetition slot is detected and if it contains the allowed code word, reception is accepted. Or, the repetition slot and the first slot are detected in a diversity manner.

With regard to coding, in the above-described first aspect of this invention the same data is re-transmitted as such in the following slot. This is the simplest manner in which to obtain the desired diversity gain. However, and in accordance with this aspect of the invention, STCM is modified for achieving even further diversity gain. The modified STCM may be referred to as TTCM (Time-Time Coded Modulation). The modification may be considered to provide a combination of coding and then interleaving into two time slots. There are several TTCM coding possibilities. The code for 8PSK modulation (Fig. 9) that was simulated gives approximately a 1.5dB gain over simple retransmission, without any bandwidth reduction or any increase in complexity. The concept of TTCM is expandable for all digital modulation methods. Note that a code with memory would provide even more diversity gain, but at the cost of an increase in receiver complexity.

It is also possible to use the two slots (i.e., first slot and the repeated slot) as a single, longer slot having the original number of data bits, but with a significantly greater number of bits used for channel coding. The coding gain of such an extended, "heavier" channel code is expected to exceed the gain of TTCM.

Having given an overview of this aspect of the invention, a detailed description of preferred embodiments is now provided. The system model used for simulations is based on the IS-136 system, more particularly an enhanced

version of IS-136 (TIA IS-136, Rev. C) that is currently being proposed. In this proposed system a forward time slot appears as shown in Fig. 14, and is modulated using 8PSK modulation. However, it should be noted that the teachings of this invention are not limited to only this one particular type of modulation, and could be practiced using a number of other types, such as $\Pi/4$-shift DQPSK modulation.

Referring to Fig. 7, there is shown a simplified IS-136 simulation model. Two random binary sources SLOT1 DATA and SLOT3 DATA are provided. The TT-Coded Modulator 110 represents a combined time-time coder and an 8PSK modulator. The Frame Formatter 112 is assumed to form IS-136 Digital Traffic Channel (DTCH) frames. The TX-Filter 114 is a square root raised cosine filter with a roll-off factor 0.35, as specified in IS-136. The Channel block 116 represents a frequency flat Rayleigh faded channel. The fading spectrum is assumed to be Classical Jakes. The Receiver 118 represents the receiver that receives the output of the channel 116 (see Fig. 8).

In operation, the data of slot 1 is transmitted twice in separate slots. As was mentioned above, the greater the distance between the two slots the less correlated are the amplitudes of the receiver diversity branches. In the simulations, however, two consecutive slots were used for simplicity. The correlation between the two slots is seen in the slow fading speeds. The data of the third slot is simply modulated to a regular 8PSK signal. The TT-coded modulator block 110 performs the time-time coding of the two slots (first slot and the repeat) and modulates the binary data into the 8PSK signal (Fig. 9). In the 8PSK signal constellation diagram adjacent constellation points differ only by one bit, i.e. the constellation diagram is gray coded. The modulated data is provided to the frame formatter 112 and then to the filter 114 where the signal is transmit filtered with the square root raised cosine filter. It should be noted that the order of TT-coded modulator 110 and the frame formatter 112 may be changed depending on the implementation, while still achieving the same result.

The receiver 118 performs the joint detection of the two consecutive slots. The joint detection is done optimally by the use of Maximum Ratio Combining (MRC). In the simulations the Channel State Information (CSI) was known, and the receiver 118 that was used was thus made optimum for the known channel. This implies that the results discussed below are optimum results for both simulated TT-codes. In practice, the receiver performance may be slightly degraded since it must estimate the CSI. The initial channel estimation is made from the known data fields of a slot. If the slot is long compared to the fading speed then decision directed or blind channel estimation algorithms, or some other suitable algorithm, may be used.

Fig. 8 illustrates the presently preferred structure of the diversity receiver 118, which includes first and second channel estimators 118a, 118b and a joint detector 118c. The joint detector 118c can output hard decisions directly, not soft decisions as in the above-described first aspect of this invention. There are, however, many possible techniques to perform the signal detection, such as the post-detection combining technique disclosed above in reference to Fig. 3B. In the approach of Fig. 8 joint detection of the two transmitted slots is accomplished, and it does not matter whether TT-coding is used for the receiver 118 to operate successfully.

Figs. 12A-12F, collectively referred to below as Fig. 12, are graphs showing simulation results of a time diversity embodiment of this invention, wherein in the simulations of Figs. 12A, 12B, 12C the repetition code of Fig. 10 was used, while in the simulations of Figs. 12D, 12E, 12F the time-time (TT) code of Fig. 11 was used.

Fig. 11 depicts one time-time (TT) code in accordance with an embodiment of this invention, wherein symbol 0 is mapped to symbol 0 of slot 1 and to symbol 0 of slot 2, symbol 1 is mapped to symbol 1 of slot 1 and symbol 5 is mapped to slot 2, etc. It is expected that a similar result could be obtained by a re-mapping of the even symbols: i.e., symbol 0 is mapped to symbol 0 of slot 1 and symbol

4 of slot 2, symbol 1 is mapped to symbol 1 of slot 1 and to symbol 1 of slot 2, etc. However, it should be noted that for obvious reasons a remapping of both the odd and the even symbols will not be as effective, and will yield the same diversity gain as the simple repetition shown in Fig. 10..

Antenna switching diversity was also simulated. In the upper right hand corner of each graph is a legend, wherein tt-code=0, antd=1 signifies that in that simulation the tt-code of Fig. 11 was not used, but antenna diversity was used instead, while dd=1, antd=0 signifies that in that simulation the simple repetition code of Fig. 10 was used, but antenna diversity was not on. Also simulated was an 8PSK modulated signal in a flat fading environment, but without any coding for comparison purposes. These performance curves represent the situation where tt-code or dd=0 and antd=0. All the simulation results are over 10,000 IS-136 full rate frames. When slot repetition is used the energy gain seen by the mobile station is 3dB, since it receives the same slot twice. As such, in Fig. 12 whenever slot repetition was used, i.e. tt-code or dd is on, 3dB was subtracted from the results, i.e. what is graphed is only the diversity gain. Therefore, it should be kept in mind that the actual gain seen by the mobile station 10 in these situations is 3dB better than that shown in the graphs of Fig. 12.

It should be noted that in these simulations the channel was known, and as such the slot format had no impact on the results. The slot format that was assumed was a 162 symbol slot containing 130 data symbols. This implies that the confidence limit of the simulations is a Bit Error Rate (BER) of $2.5*10^{-5}$. Channel coding was not used in the simulations.

A comparison was made between the algorithm of this invention and 8-PSK performance in flat fading. The simulation results show that at slow fading speeds, i.e. in the lower band and at low velocity, the correlation between consecutive slots is high. This being the case, the optimum diversity gain obtained from slot repetition is only about 1dB. The use of the tt-code, however,

increases the distance between transmitted symbols. As such, the tt-code performs 1.5dB better than simple retransmission. As the fading speed becomes larger the diversity gain increases until it saturates. The performance of algorithm of this invention was simulated at various fading speeds. The achievable diversity gain with the two codes of Fig. 10 and Fig. 11, at various fading speeds, is shown in Fig. 13. The 3dB energy gain can be added to these results.

Fig. 13 shows that TTCM increases the diversity gain of simple repetition code by 1.5dB without any bandwidth loss or complexity increase. The TTCM code shown here has no memory. However, and as was noted above, providing a time-time code with memory would increase the diversity gain even more, but at the expense of increased receiver complexity.

In summary, the use of the teachings of this aspect of the invention: (a) enables smaller correlation at low speeds to be achieved with longer delay; (b) enables diversity gain to be increased by coding; and (c) more that two branch diversity to be used.

Improved performance can be achieved in two ways. Since soft decisions are not generally optimal, there is some information loss. If decision directed channel estimation is used the channel estimation variance is dependent on the symbol error rate. If detection is done separately, there can be a quite large symbol error rate in the channel estimation. However, and in accordance with this aspect of the invention, when both diversity branches are detected jointly, the symbol error rate is notably improved due to the presence of diversity gain.

During the simulations the performance of the combining algorithm was studied both in interference and noise limited flat channels. At 8 km/h with an 800 MHz carrier 4dB gain was measured, as compared to the detection of one slot. While the total transmitted power with the repetition is doubled there is 1dB diversity gain and a further 1.5dB gain from the use of TTCM. At 100 km/h with

a 1900 MHz carrier the total gain was about 9.5dB, which implies a 6.5dB diversity gain. Keeping in mind that the complexity of the system is just slightly increased, the increase in gain is very significant.

In general, in one aspect of this invention the repeated time slots can be copied versions of the original time slot. The more repetitions that are used, and the longer the time difference, the better is the diversity gain. In a further aspect of this invention the STCM is modified, and the modification is referred to as TTCM. In accordance with this further aspect of the invention the repeated slots are coded with the different code, thereby providing coding gain in addition to the diversity gain.

For example, and referring to Fig. 16, it can be seen that up to N TT-code modulators and associated interleavers can be used to provide an original time slot and N-1 repeats of the original time slot, with the information in the repeated time slots being differently coded.

The use of this invention also enables power savings to be achieved by a number of different techniques. For example, and referring to Fig. 17, the receiver can detect the repeated slot(s) until the CRC check is passed (or until some predetermined number of repeated slots are received). If the CRC check is passed before the predetermined number of repeated time slots are received, then the reception and/or detection of subsequent time slots can be inhibited, thereby saving power. Further by example, and referring to Fig. 18, if the CRC check fails the method can instead combine the power of the newly received time slot with earlier received time slot(s) in order to obtain an improved detection. Other possibilities exist as well. For example, two slots can be received and combined, and the CRC check made on the combined time slots.

A number of different detection techniques have been described, such as adding or otherwise combining soft decisions, using a joint detector, and selection techniques. Other detection techniques can be used as well.

Furthermore, and as was indicated previously, the above-presented algorithm that minimizes the metric can be replaced by another technique for accomplishing the joint detection and combining the information from more than one time slot. That is, in other embodiments of this invention other algorithms can be used for combining information from more than one time slot, and the teachings of this invention are thus not to be construed to be limited to the use of only the algorithm described above.

Thus, while the invention has been particularly shown and described with respect to a number of preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the scope and spirit of the invention.

The scope of the present disclosure includes any novel feature or combination of features disclosed therein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed by the present invention. The applicant hereby gives notice that new claims may be formulated to such features during prosecution of this application or of any such further application derived therefrom.

CLAIMS

1. In a wireless radiotelephone system comprising a base station and a mobile station, a method that includes the steps of:

transmitting a time slot and a repeat of the time slot from the base station to the mobile station;

selectively receiving the time slots, detecting soft information from each of the time slots, and providing a combination of the soft information to a channel decoder; and

performing channel decoding using the combination of soft information.

2. A method for improving TDMA mobile station receiver performance, comprising steps of:

receiving a traffic/control channel message having a slotted frame structure;

demodulating and then soft-decision decoding a first time slot;

storing the soft information from the first time slot; and

subsequently using the stored soft information with soft information derived from a subsequently received whole or partial second time slot.

3. A method as in claim 2, wherein the step of subsequently using is selectively performed based on a determination as to whether the first time slot was received without error.

4. A method as in claim 2 or 3, wherein the step of subsequently using is selectively performed based on a determination as to a channel received error rate.

5. A method as in claim 2, 3 or 4 wherein the step of subsequently using is selectively performed based on at least one criterion, and if the step of subsequently using is not performed, the method includes a step of placing the mobile station in a reduced power state of operation at least during a time that the second time slot would be received.

6. A method as in any of claims 2 to 5, and further comprising a step of decoding the soft information selected from one of the first or second time slots or from a combination of the first and second time slots.

7. A method as in any of claims 2 to 6, and further comprising a step of determining in the mobile station if the second time slot contains a repeat of the information contained in the first time slot, and wherein the step of subsequently using is not executed for the case where the mobile station determines that the second time slot does not contain a repeat of the information contained in the first time slot.

8. A method as in any of claims 2 to 7, wherein the second time slot is received only during a time that a Discontinuous Transmission (DTX) mode of operation is in effect.

9. A method as in claim 8, and further comprising a step of performing a Mobile Assisted Handoff measurement after receiving the second time slot.

10. A method as in any of claims 2 to 9, wherein the first and second time slots convey a control message that is specified to be repeated.

11. A method as in any of claims 2 to 10, wherein the first and second time slots convey a control message, and wherein the second time slot is transmitted only upon the mobile station indicating that the first time slot was not received with some predetermined reliability.

12. A wireless radiotelephone system, comprising:

a base station; and

a mobile station;

said base station comprising a transmitter for transmitting a time slot and a repeat of the time slot to the mobile station; and

said mobile station comprising circuitry for selectively receiving the time slots, for detecting soft information from each of the time slots, for providing a combination of the soft information to a channel decoder, and for performing channel decoding using the combination of soft information.

13. A method for improving TDMA mobile station receiver performance, comprising steps of:

transmitting, from a base station, a control channel message in a slotted frame structure;

receiving, demodulating and then soft-decision decoding a first time slot in the mobile station;

storing the soft information from the first time slot;

receiving, demodulating and then soft-decision decoding a second time slot wherein the control channel message is repeated;

storing the soft information from the second time slot; and

transmitting a request to the base station for a retransmission of the control channel message if one or both of the stored soft information is below a threshold quality value.

14. In a wireless radiotelephone system comprising a base station and a mobile station, a method comprising steps of:

transmitting a time slot and a repeat of the time slot from the base station to the mobile station;

selectively receiving the first and second time slots, detecting soft information from each of the time slots, and providing a combination of the soft information to a channel decoder; and

performing channel decoding using the combination of soft information while periodically retuning a receiver of the mobile station to measure the signal strength of another frequency channel.

15. A method for operating a wireless communication system, comprising steps of:

transmitting a time slot and a repeat of the time slot to a channel, each of the transmitted time slots being modulated to convey the same information;

receiving the time slot and the repeat of the time slot with a diversity receiver;

demodulating and then processing the received time slot and the repeat of the time slot with a first channel estimator and with a second channel estimator, respectively; and

performing a joint detection on the received time slot and the repeat of the time slot so as to determine the information.

16. A method as in claim 15, wherein the step of performing a joint detection is accomplished in accordance with the following:

Minimize metric

$$\Gamma = \sum_{i=1}^{L} k_{i,k} \left| y_{i,k} - c_{i,k} \partial_i \right|^2$$

where Γ is a minimized metric, $k_{i,k}$ is a weight based on a selected combining algorithm, $y_{i,k}$ is a received sample from diversity branch (slot) i at time k, $c_{i,k}$ is a corresponding channel estimation, ∂_i is a trial symbol for time slot i, and L is equal to the number of repeated slots.

17. A method as in claim 15 or 16, wherein the step of transmitting includes the initial step of applying time-time coded modulation to a signal to be transmitted.

18. A method as in any of claims 15 to 17, wherein the modulation is 8PSK modulation.

19. A method as in any of claims 15 to 18, wherein each time slot contains 162 symbols and has 130 data symbols.

20. A wireless communication system, comprising:

a base station comprising a transmitter for transmitting a time slot and a repeat of the time slot to a channel; and

a mobile station comprising a diversity receiver for receiving the time slot and the repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot, said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for determining the information.

21. A wireless communications system as in claim 20, wherein the joint detection is accomplished in accordance with the following:

Minimize metric

$$\Gamma = \sum_{i=1}^{L} k_{i,k} \left| y_{i,k} - c_{i,k} \partial_i \right|^2$$

where Γ is a minimized metric, $k_{i,k}$ is a weight based on a selected combining algorithm, $y_{i,k}$ is a received sample from diversity branch (slot) i at time k, $c_{i,k}$ is a corresponding channel estimation, ∂_i is a trial symbol for time slot i, and L is equal to the number of repeated slots.

22. A wireless communications system as in claim 20 or 21, wherein the base station comprises a modulator for applying time-time coded modulation to a signal to be transmitted.

23. A wireless communications system as in any of claims 20 to 22, wherein the demodulator is an 8PSK demodulator.

24. A wireless communications system as in any of claims 20 to 23, wherein each time slot contains 162 symbols and has 130 data symbols.

25. A wireless communication system, comprising:

a base station comprising a transmitter for transmitting information in a time slot and a repeat of the time slot, said base station comprising an 8PSK modulator and means for time-time coding the information, wherein each time slot contains 162 symbols and has 130 data symbols; and

a radiotelephone comprising a receiver for receiving the time slot and the repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot, said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for extracting the information.

26. In a wireless radiotelephone system comprising a base station and a mobile station, a method that includes the steps of:

transmitting a time slot and, at a subsequent time, at least one repeat of the time slot from the base station to the mobile station;

receiving the time slots; and

determining information transmitted to the mobile station by combining the time slot and the at least one repeat of the time slot.

27. A method as in claim 26, wherein the time slot and the at least one repeat of the time slot are coded in the same manner.

28. A method as in claim 26 or 27, wherein the time slot and the at least one repeat of the time slot are coded in a different manner so as to provide coding gain in addition to time diversity gain.

29. A method as in claim 28, wherein the time slot and the at least one repeat of the time slot are coded using TTCM.

30. A method as in any of claims 26 to 29, wherein the step of determining uses soft symbol decisions obtained from the time slot and the at least one repeat of the time slot.

31. A method as in any of claims 26 to 30, wherein the step of determining uses hard symbol decisions obtained from a joint detection of the time slot and the at least one repeat of the time slot.

32. A mobile station for use in a Time Division Multiple Access (TDMA) communication system, wherein the mobile station comprises circuitry for selectively receiving a time slot and a repeat of the time slot, for detecting soft information from each of the time slots, for providing a combination of the soft information to a channel decoder, and for performing channel decoding using the combination of soft information.

33. A mobile station for use in a Time Division Multiple Access (TDMA) communication system, wherein the mobile station comprises a diversity receiver for receiving a time slot and a repeat of the time slot, said diversity receiver comprising a demodulator and a processor for demodulating and then processing the received time slot and the repeat of the time slot, said processor comprising a first channel estimator and a second channel estimator, and a joint detector for performing a joint detection on the received time slot and the repeat of the time slot for determining the information contained therein.

34. A base station for use in a Time Division Multiple Access (TDMA) communication system, wherein the base station comprises means for automatically transmitting a repeat of a time slot on an adjacent vacant time slot.

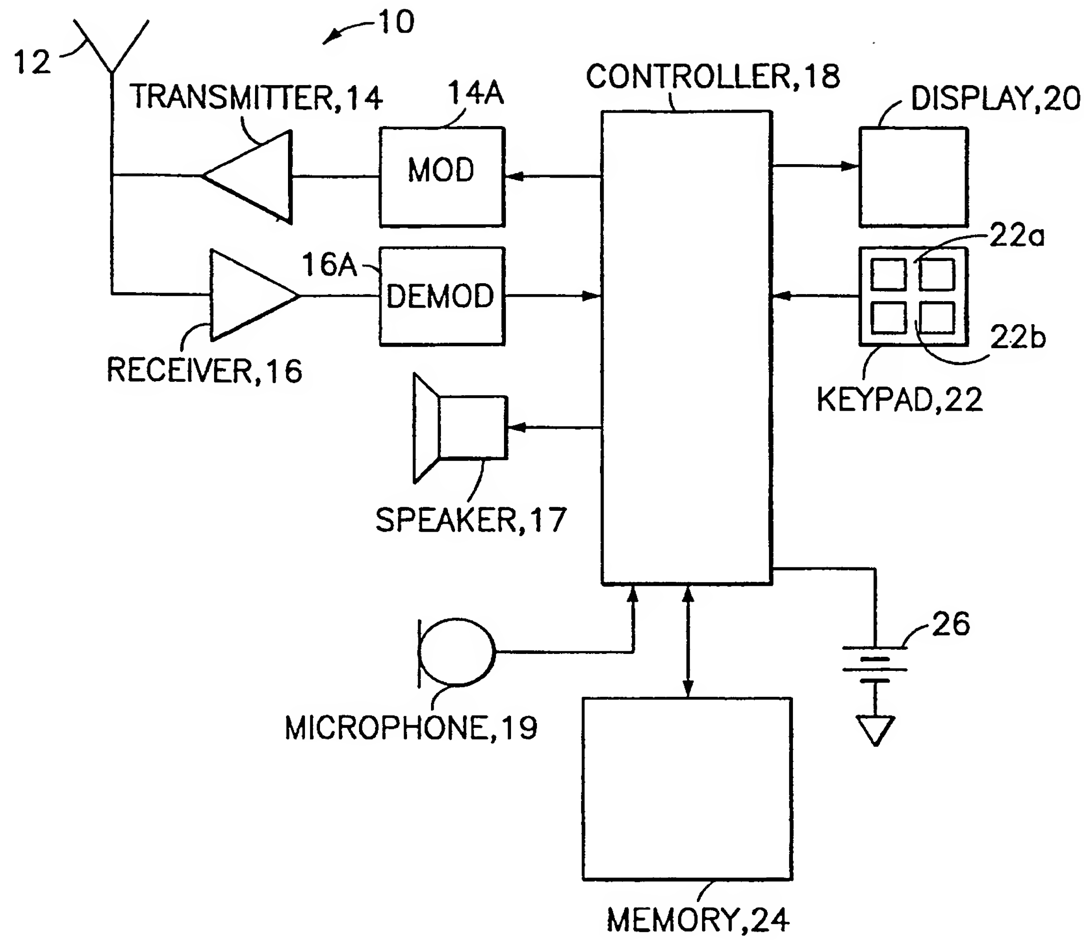
10
12
TRANSMITTER,14
14A
CONTROLLER,18
DISPLAY,20
MOD
16A
DEMOD
22a
22b
RECEIVER,16
KEYPAD,22
SPEAKER,17
26
MICROPHONE,19
MEMORY,24

FIG. 1

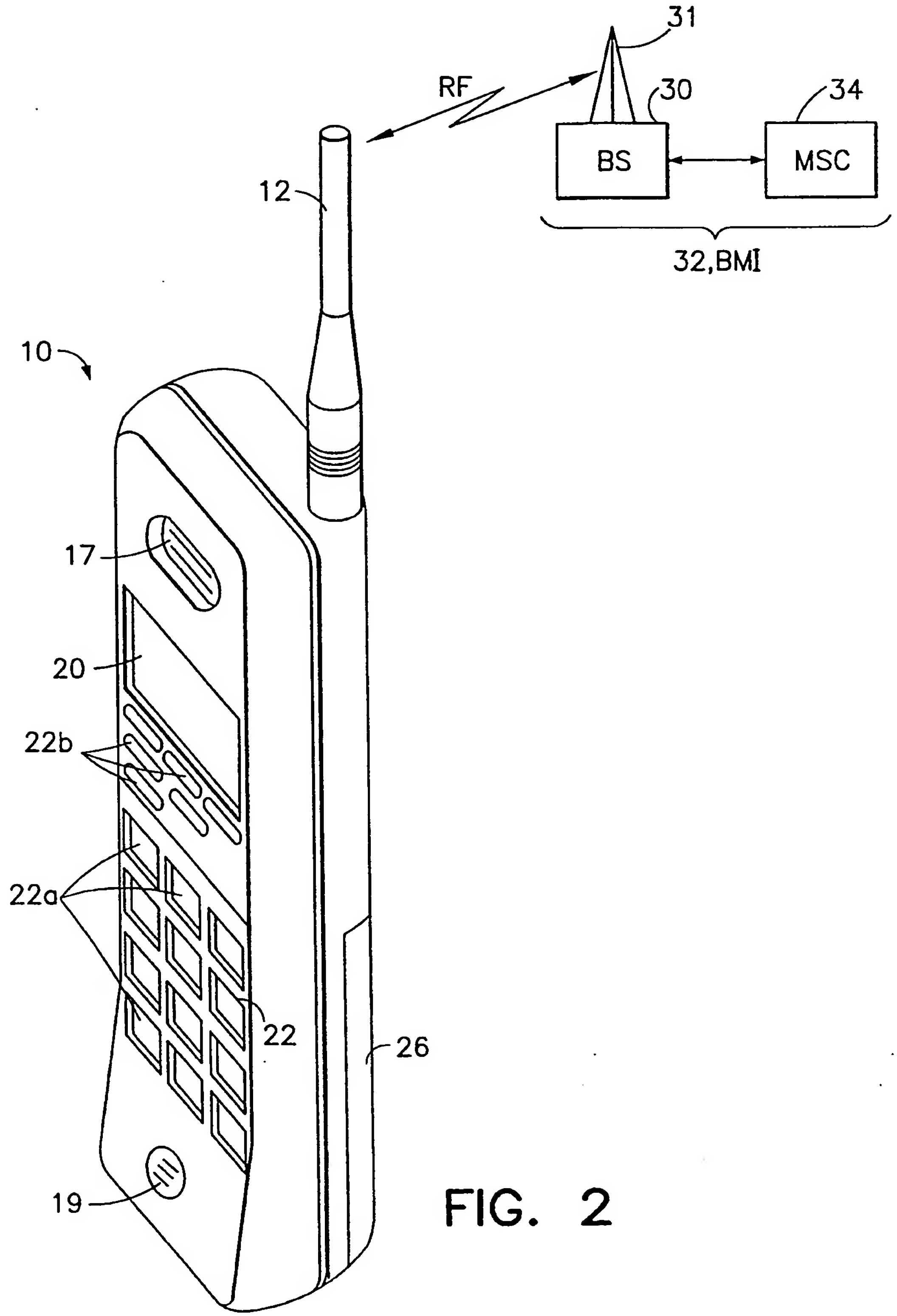

FIG. 2

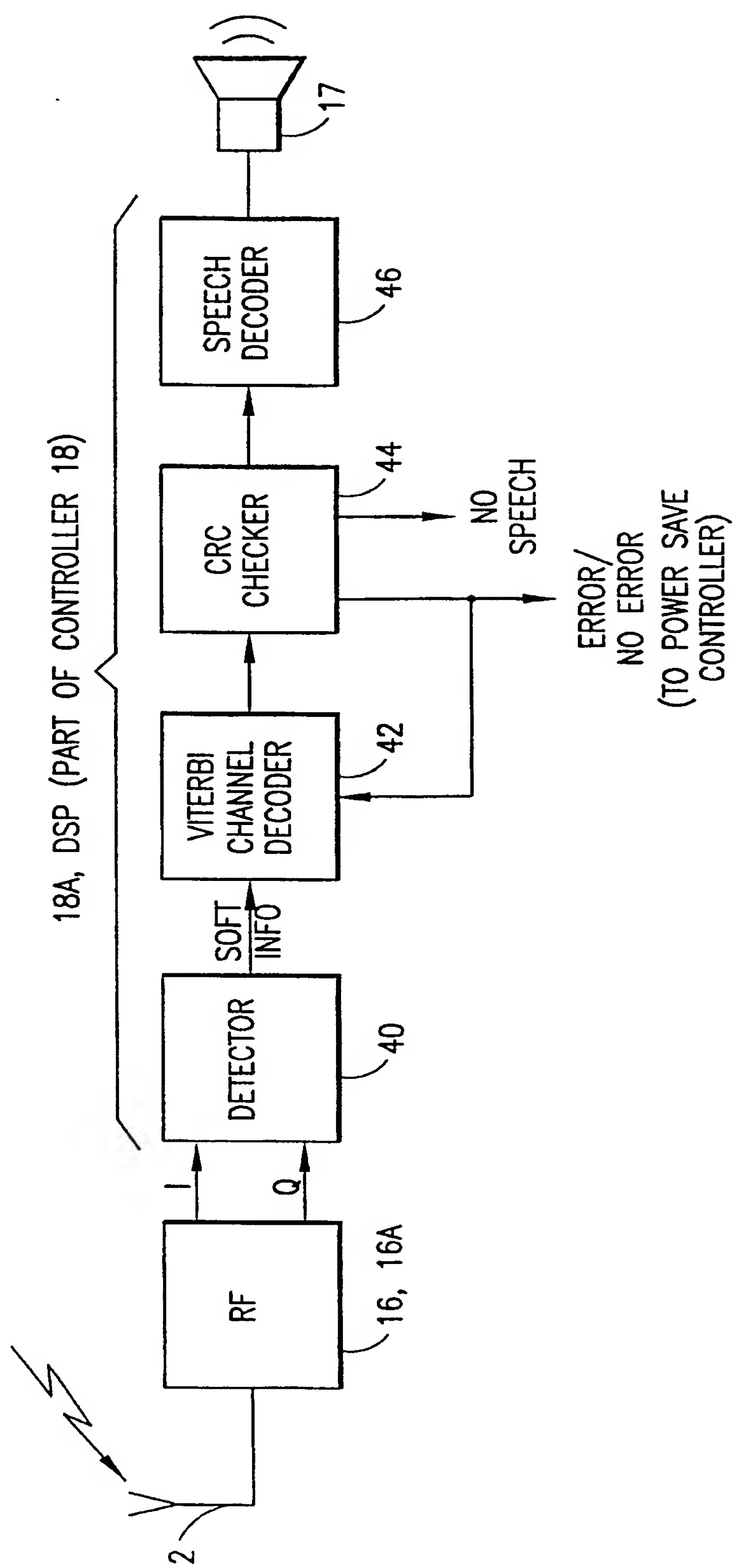
12
RF
16, 16A
I
Q
DETECTOR
40
SOFT INFO
VITERBI CHANNEL DECODER
42
CRC CHECKER
44
NO SPEECH
ERROR/ NO ERROR (TO POWER SAVE CONTROLLER)
SPEECH DECODER
46
17
18A, DSP (PART OF CONTROLLER 18)

FIG.3A

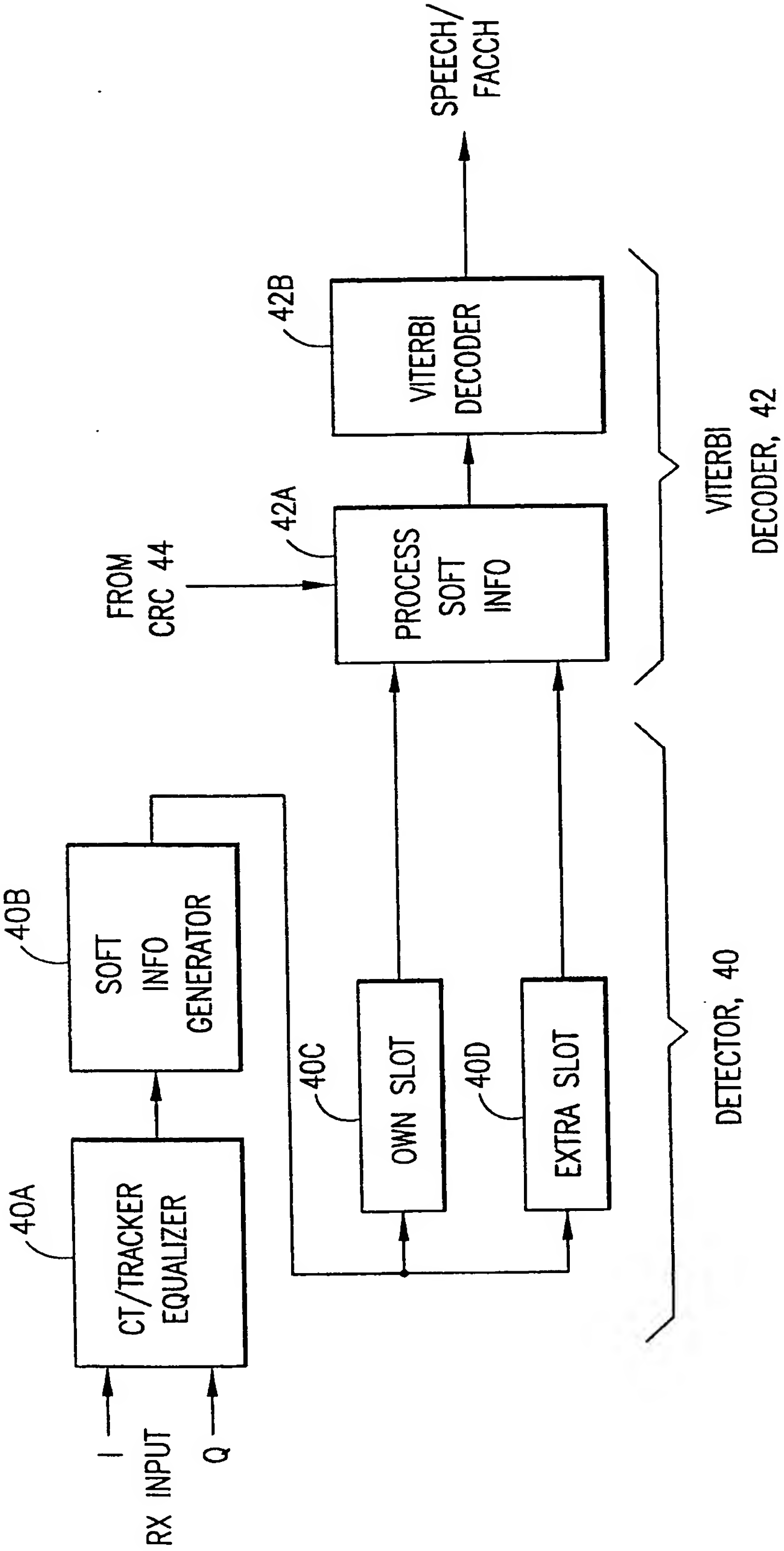
SPEECH/
FACCH
42B
VITERBI
DECODER
42A
FROM
CRC 44
PROCESS
SOFT
INFO
VITERBI
DECODER, 42
40B
SOFT
INFO
GENERATOR
40A
CT/TRACKER
EQUALIZER
40C
OWN SLOT
40D
EXTRA SLOT
DETECTOR, 40
RX INPUT
I
Q

FIG.3B

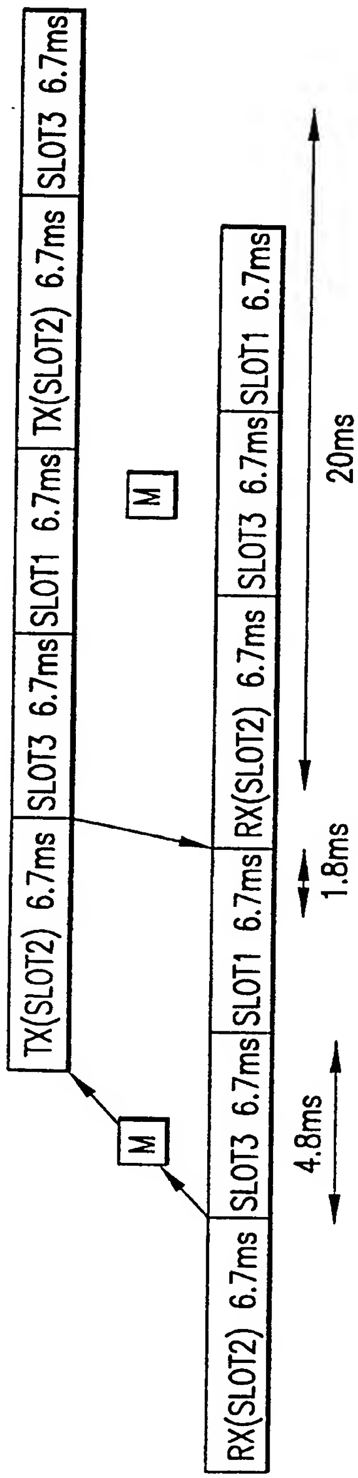
TX(SLOT2) 6.7ms
SLOT3 6.7ms
SLOT1 6.7ms
TX(SLOT2) 6.7ms
SLOT3 6.7ms
M
M
RX(SLOT2) 6.7ms
SLOT3 6.7ms
SLOT1 6.7ms
RX(SLOT2) 6.7ms
SLOT3 6.7ms
SLOT1 6.7ms
4.8ms
1.8ms
20ms

FIG.4A

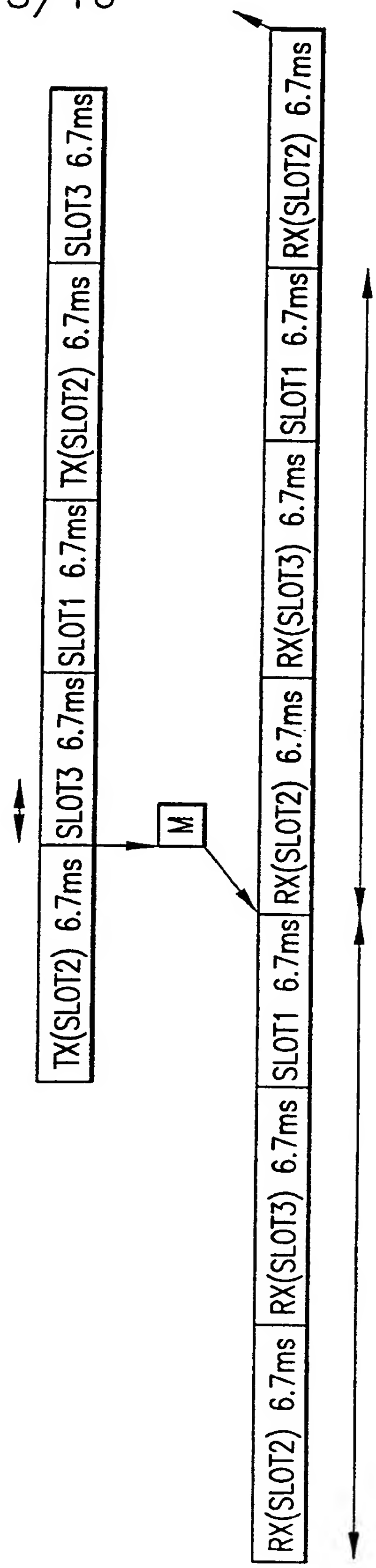
TX(SLOT2) 6.7ms
SLOT3 6.7ms
SLOT1 6.7ms
TX(SLOT2) 6.7ms
SLOT3 6.7ms
M
RX(SLOT2) 6.7ms
RX(SLOT3) 6.7ms
SLOT1 6.7ms
RX(SLOT2) 6.7ms
RX(SLOT3) 6.7ms
SLOT1 6.7ms
RX(SLOT2) 6.7ms

FIG.4B

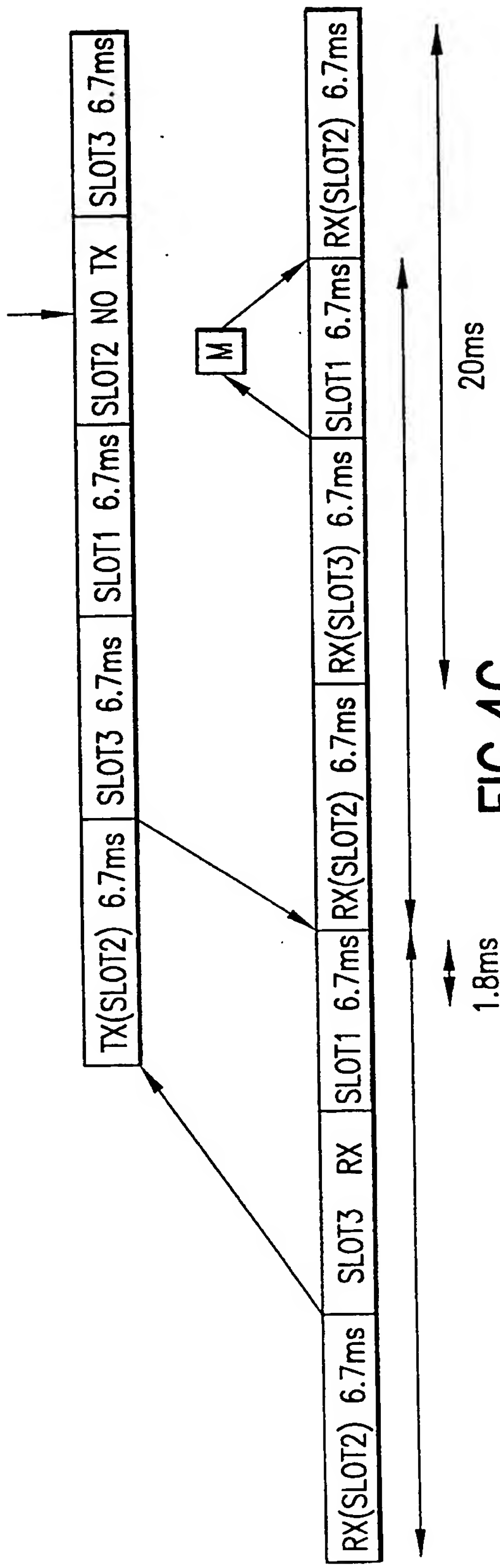
SLOT3 6.7ms
SLOT2 NO TX
SLOT1 6.7ms
SLOT3 6.7ms
TX(SLOT2) 6.7ms
RX(SLOT2) 6.7ms
RX(SLOT3) 6.7ms
SLOT1 6.7ms
RX(SLOT2) 6.7ms
SLOT1 6.7ms
SLOT3 RX
RX(SLOT2) 6.7ms
M
20ms
1.8ms

FIG.4C

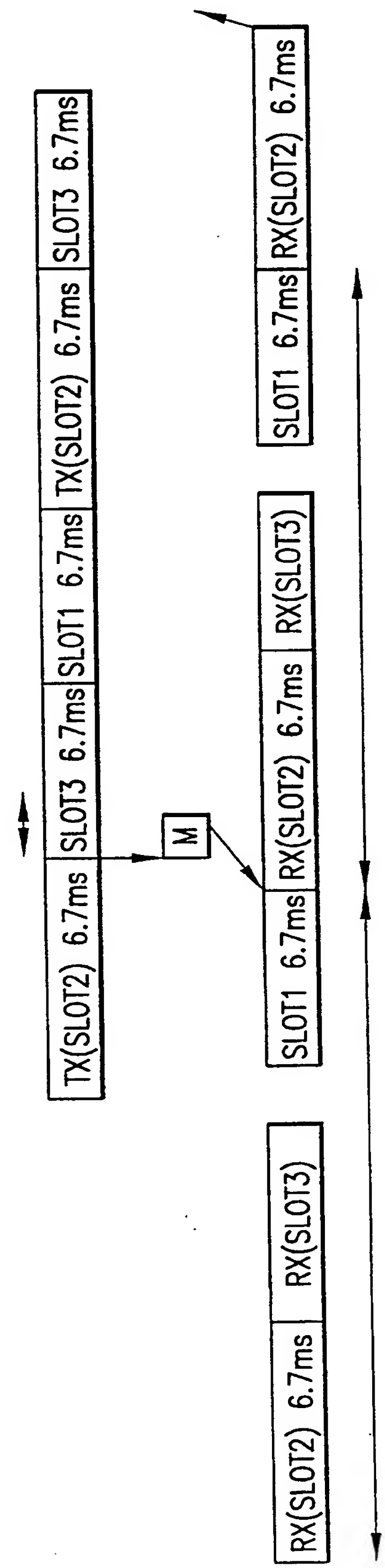
SLOT3 6.7ms
TX(SLOT2) 6.7ms
SLOT1 6.7ms
SLOT3 6.7ms
TX(SLOT2) 6.7ms
RX(SLOT2) 6.7ms
SLOT1 6.7ms
RX(SLOT3)
RX(SLOT2) 6.7ms
SLOT1 6.7ms
RX(SLOT3)
RX(SLOT2) 6.7ms
M

FIG.4D

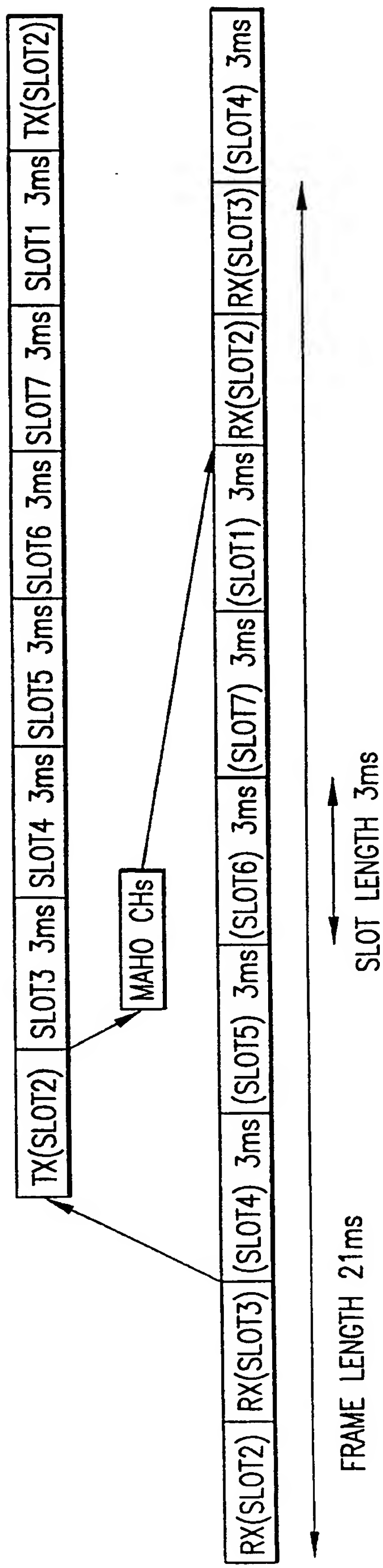
TX(SLOT2)
SLOT3 3ms
SLOT4 3ms
SLOT5 3ms
SLOT6 3ms
SLOT7 3ms
SLOT1 3ms
TX(SLOT2)
MAHO CHs
RX(SLOT2)
RX(SLOT3)
(SLOT4) 3ms
(SLOT5) 3ms
(SLOT6) 3ms
(SLOT7) 3ms
(SLOT1) 3ms
RX(SLOT2)
RX(SLOT3)
(SLOT4) 3ms
FRAME LENGTH 21ms
SLOT LENGTH 3ms

FIG.4E

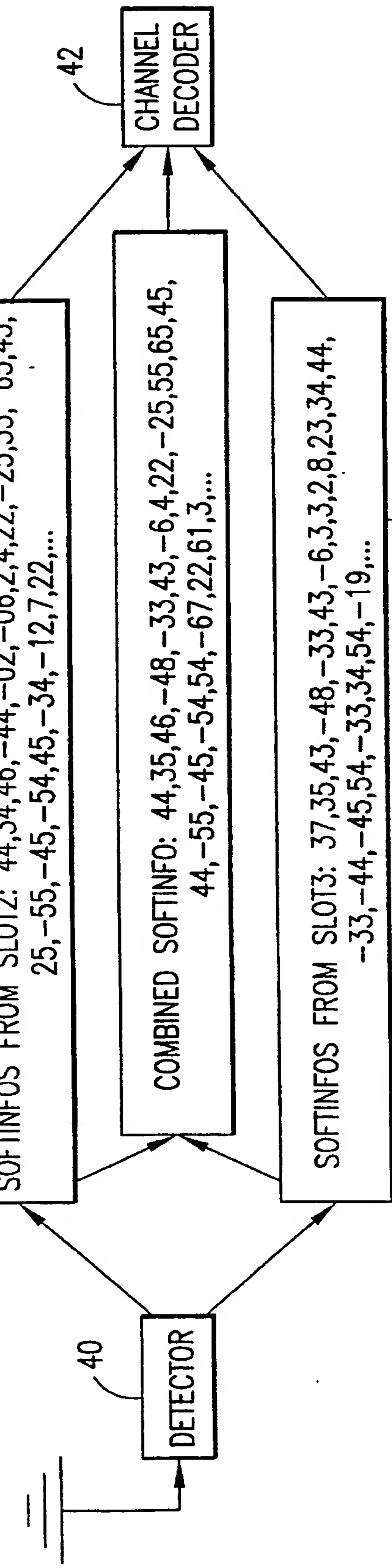
DETECTOR
40
SOFTINFOS FROM SLOT2: 44,34,46,−44,−02,−06,2,4,22,−25,55, 65,45, 25,−55,−45,−54,45,−34,−12,7,22,...
40C
COMBINED SOFTINFO: 44,35,46,−48,−33,43,−6,4,22,−25,55,65,45, 44,−55,−45,−54,54,−67,22,61,3,...
SOFTINFOS FROM SLOT3: 37,35,43,−48,−33,43,−6,3,2,8,23,34,44, −33,−44,−45,54,−33,34,54,−19,...
40D
42
CHANNEL DECODER

FIG.4F

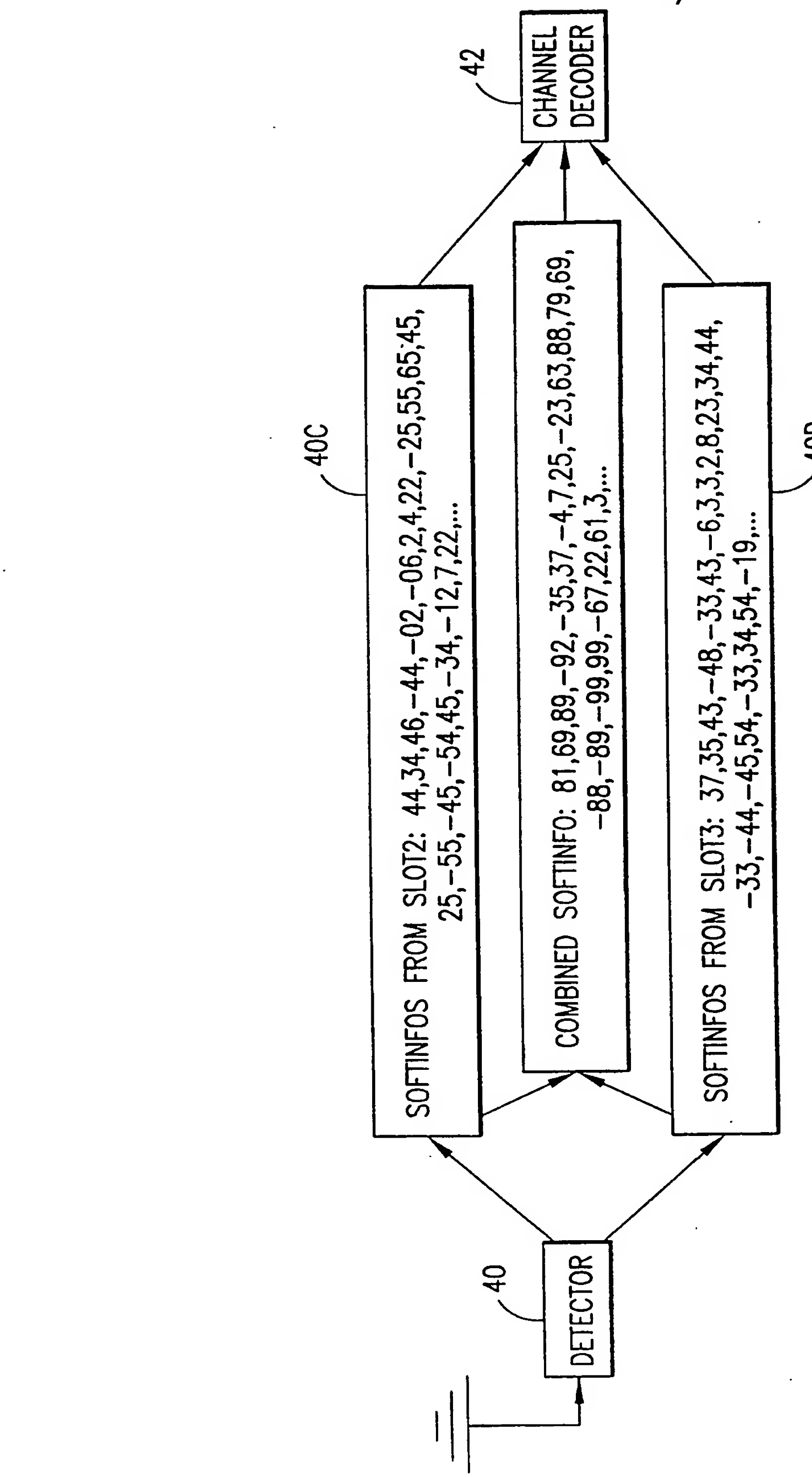
42
CHANNEL DECODER
40C
SOFTINFOS FROM SLOT2: 44,34,46,-44,-02,-06,2,4,22,-25,55,65;45, 25,-55,-45,-54,45,-34,-12,7,22,...
COMBINED SOFTINFO: 81,69,89,-92,-35,37,-4,7,25,-23,63,88,79,69, -88,-89,-99,99,-67,22,61,3,...
SOFTINFOS FROM SLOT3: 37,35,43,-48,-33,43,-6,3,3,2,8,23,34,44, -33,-44,-45,54,-33,34,54,-19,...
40D
40
DETECTOR

FIG.4G

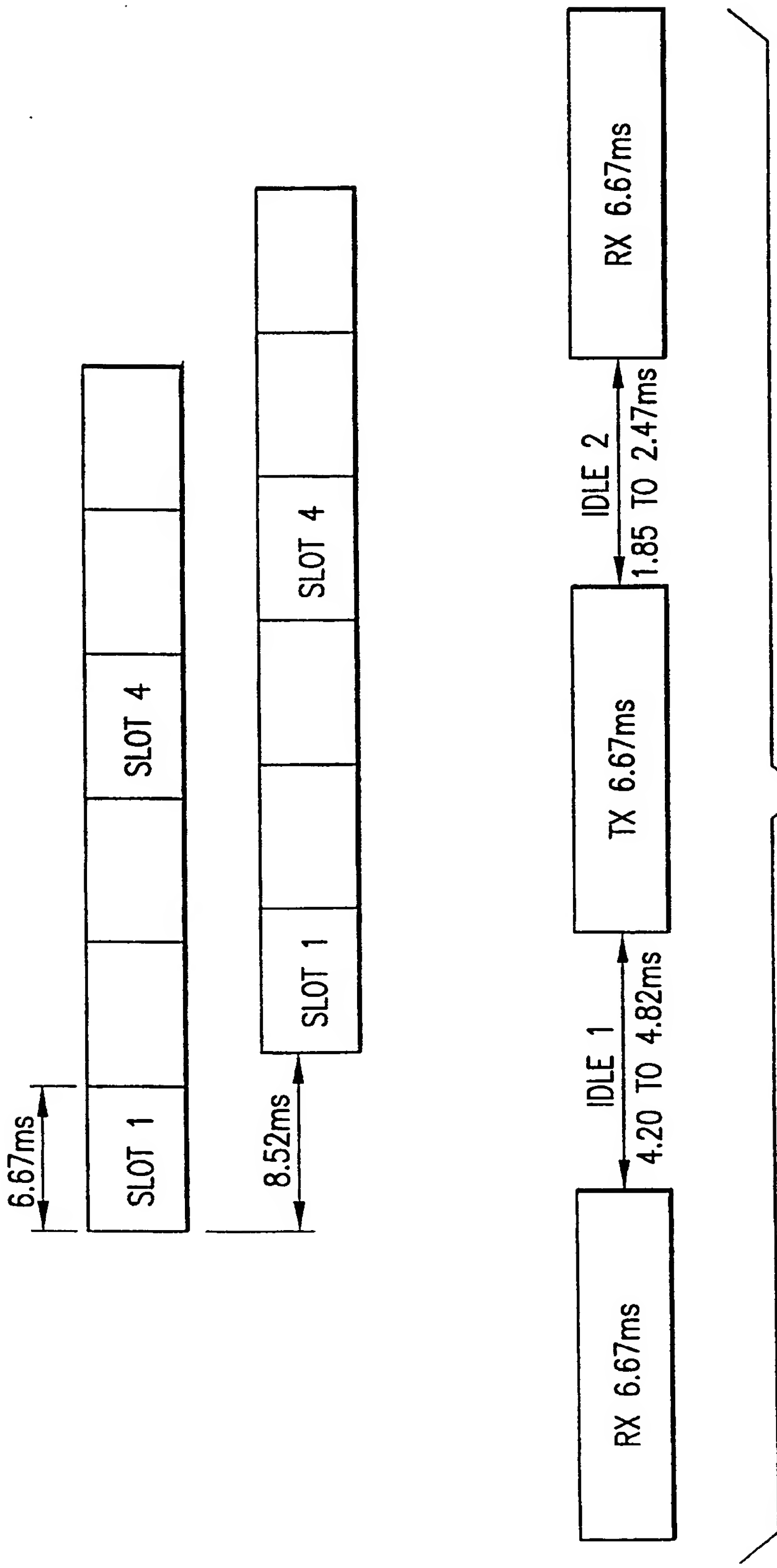
SLOT 1
SLOT 4
6.67ms
8.52ms
SLOT 1
SLOT 4
RX 6.67ms
IDLE 1
4.20 TO 4.82ms
TX 6.67ms
IDLE 2
1.85 TO 2.47ms
RX 6.67ms

FIG.5

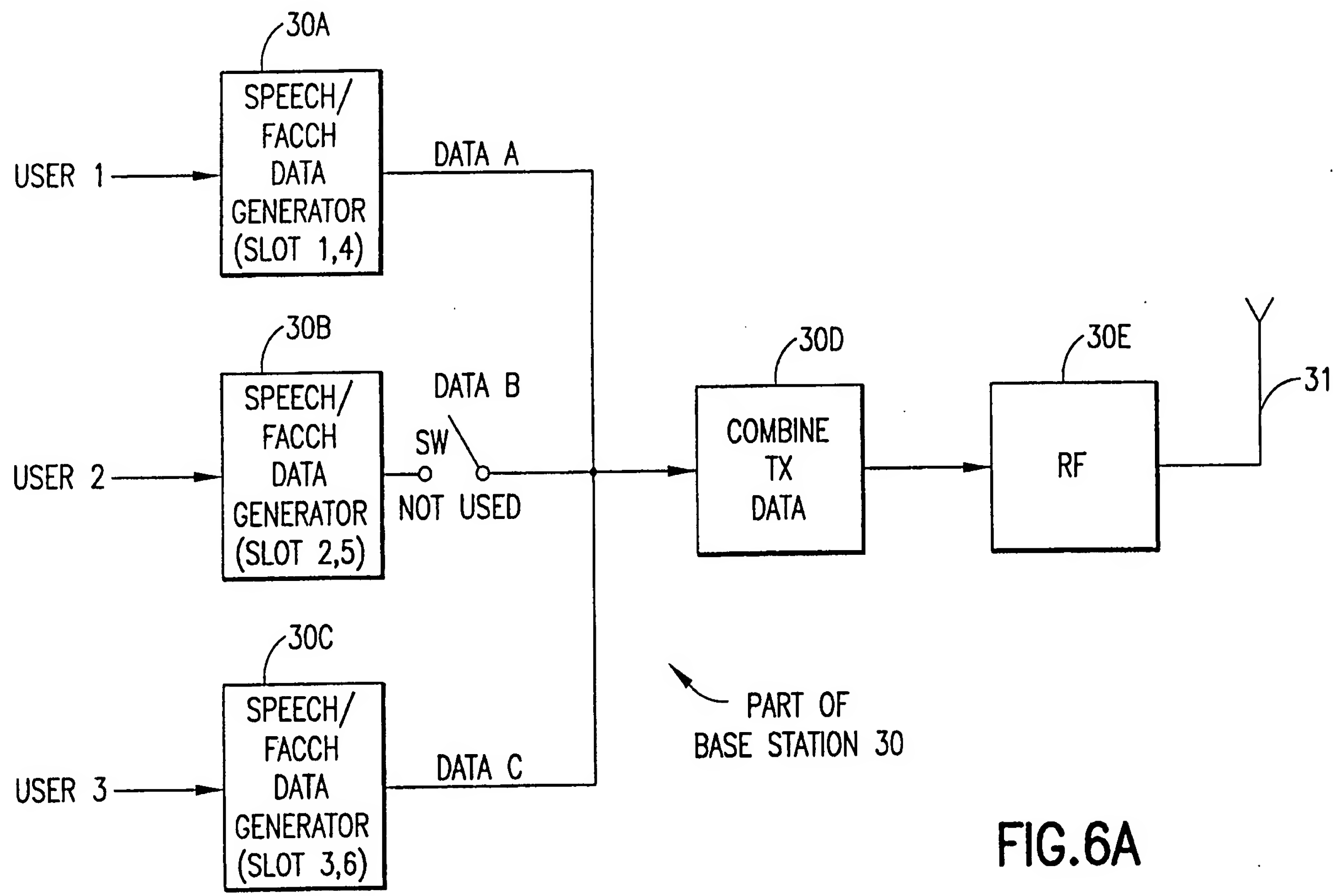
30A
SPEECH/
FACCH
DATA
GENERATOR
(SLOT 1,4)
USER 1
DATA A
30B
SPEECH/
FACCH
DATA
GENERATOR
(SLOT 2,5)
USER 2
DATA B
SW
NOT USED
30C
SPEECH/
FACCH
DATA
GENERATOR
(SLOT 3,6)
USER 3
DATA C
30D
COMBINE
TX
DATA
30E
RF
31
PART OF
BASE STATION 30

FIG.6A

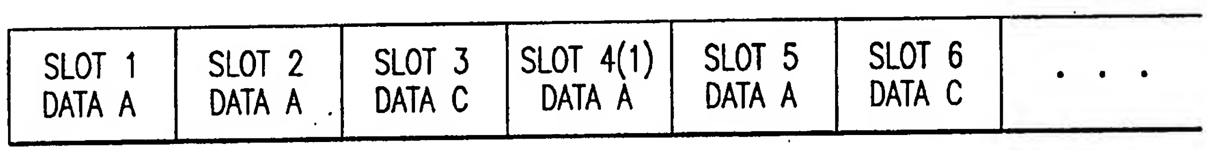
SLOT 1
DATA A
SLOT 2
DATA A
SLOT 3
DATA C
SLOT 4(1)
DATA A
SLOT 5
DATA A
SLOT 6
DATA C
. . .

FIG.6B

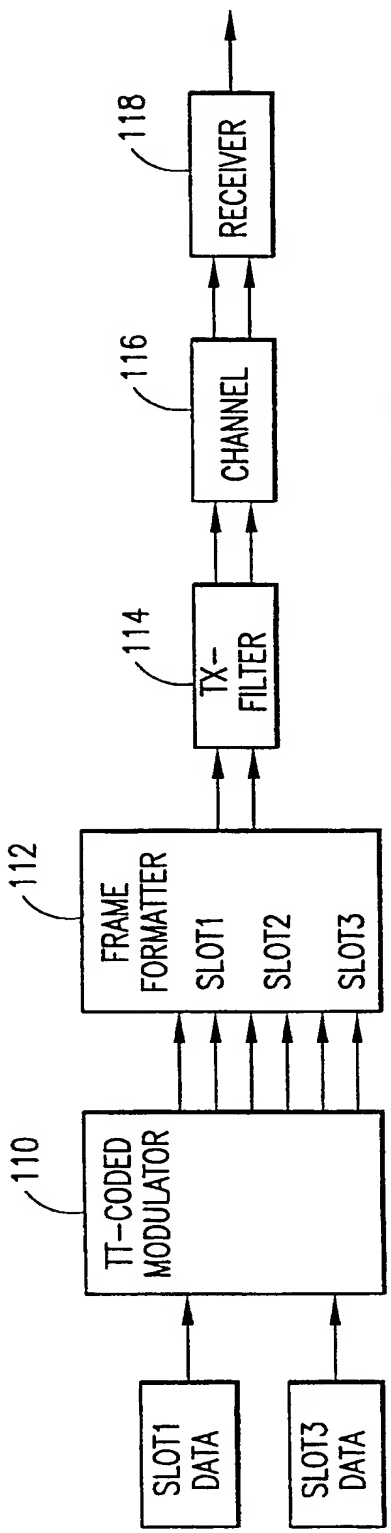
SLOT1 DATA
SLOT3 DATA
110
TT-CODED MODULATOR
112
FRAME FORMATTER
SLOT1
SLOT2
SLOT3
114
TX-FILTER
116
CHANNEL
118
RECEIVER

FIG.7

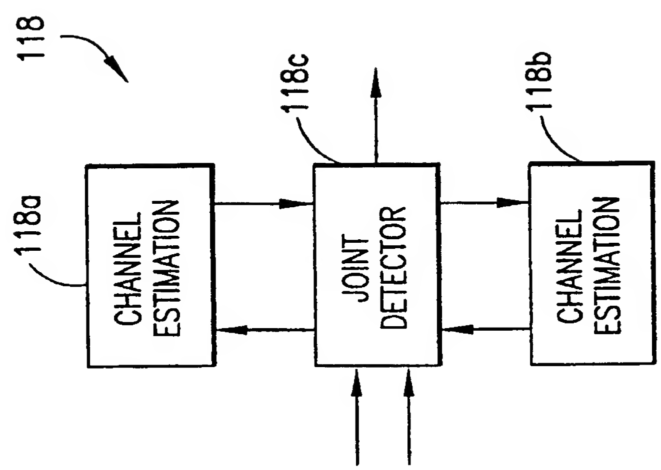
118
118a
CHANNEL ESTIMATION
118c
JOINT DETECTOR
118b
CHANNEL ESTIMATION

FIG.8

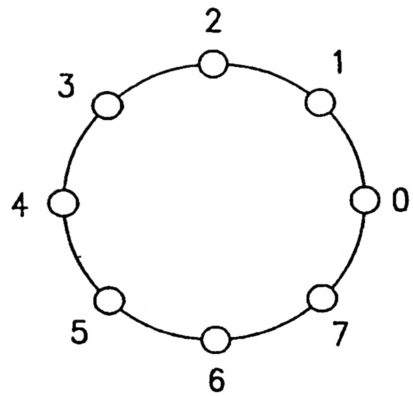

FIG.9

0	—	0	0
1	—	1	1
2	—	2	2
3	—	3	3
4	—	4	4
5	—	5	5
6	—	6	6
7	—	7	7

FIG.10

0	—	0	0
1	—	1	5
2	—	2	2
3	—	3	7
4	—	4	4
5	—	5	1
6	—	6	6
7	—	7	3

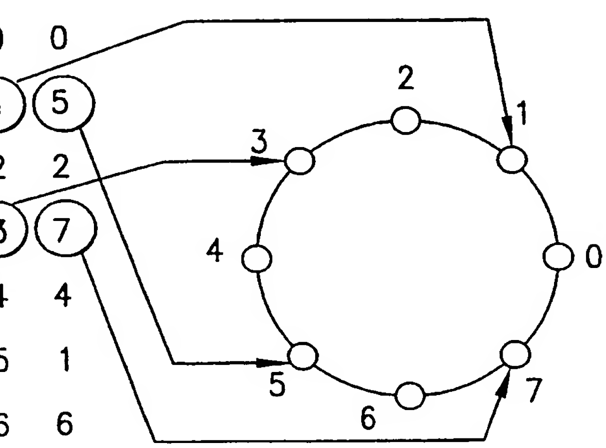

FIG.11

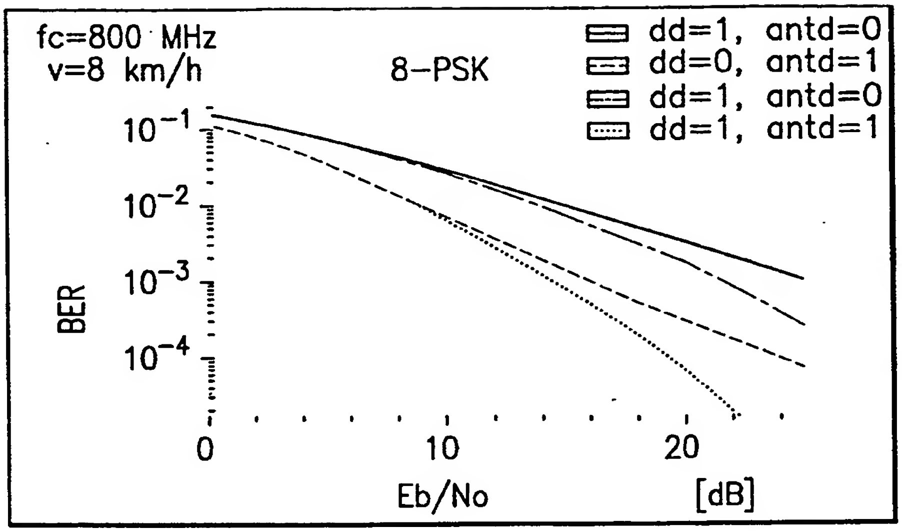

FIG.12A

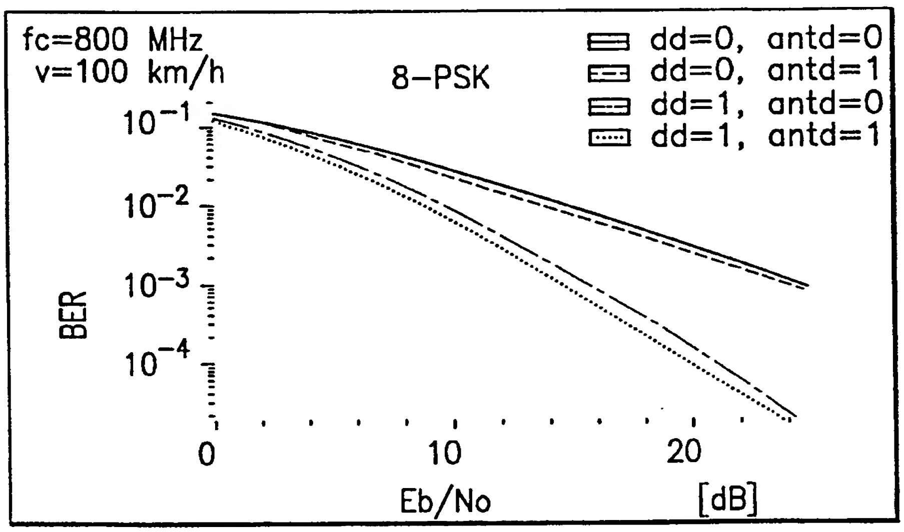

FIG.12B

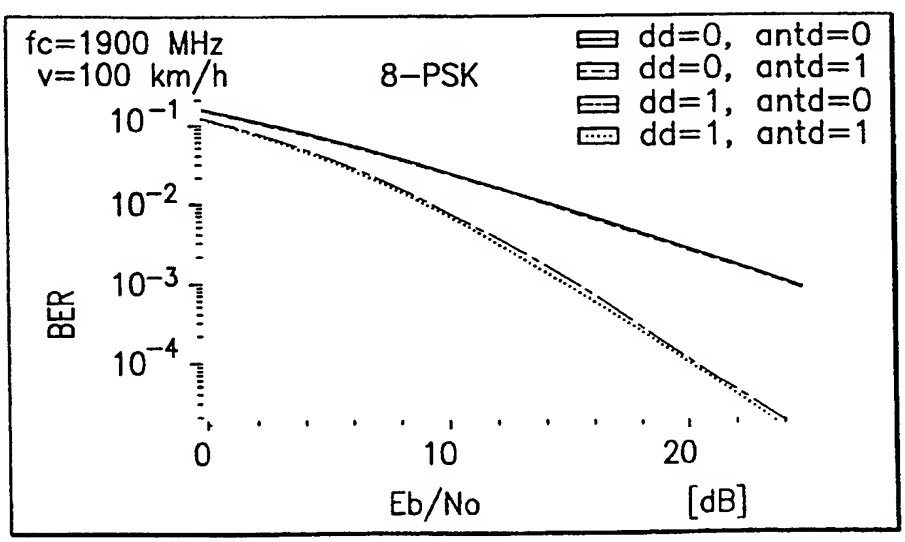

FIG.12C

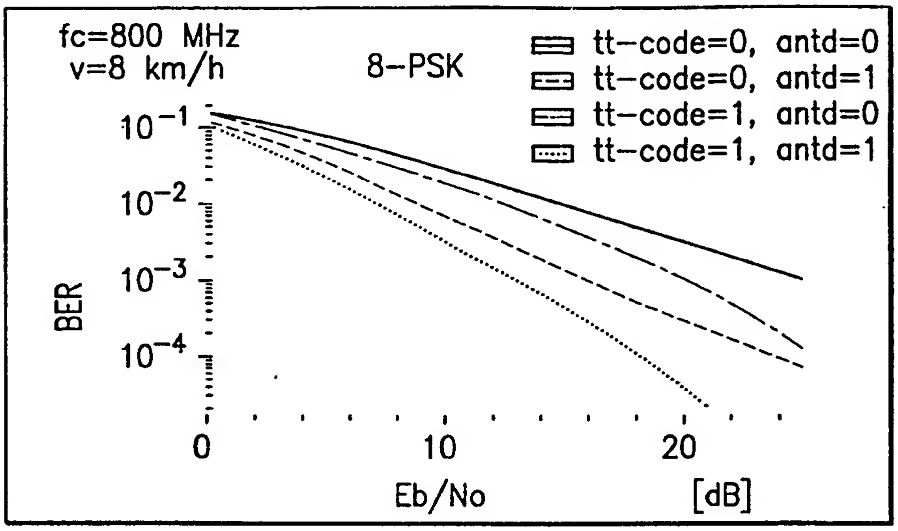

FIG.12D

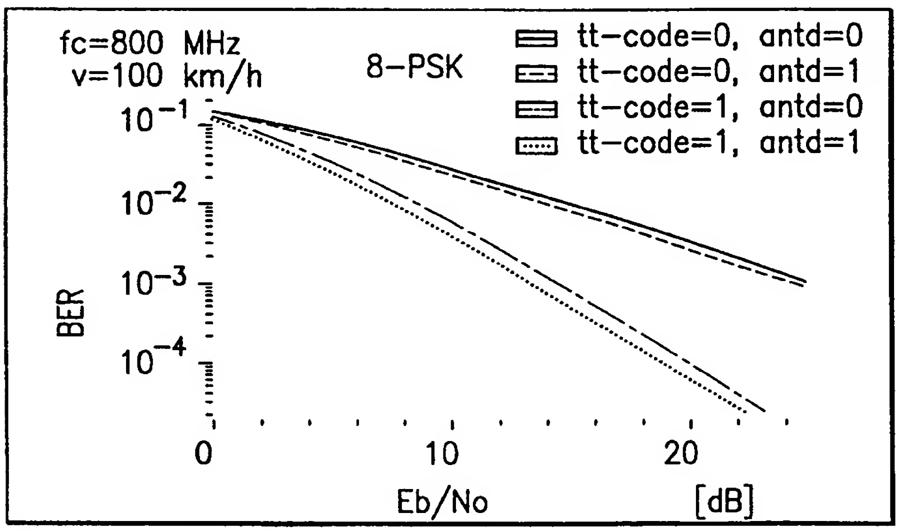

FIG.12E

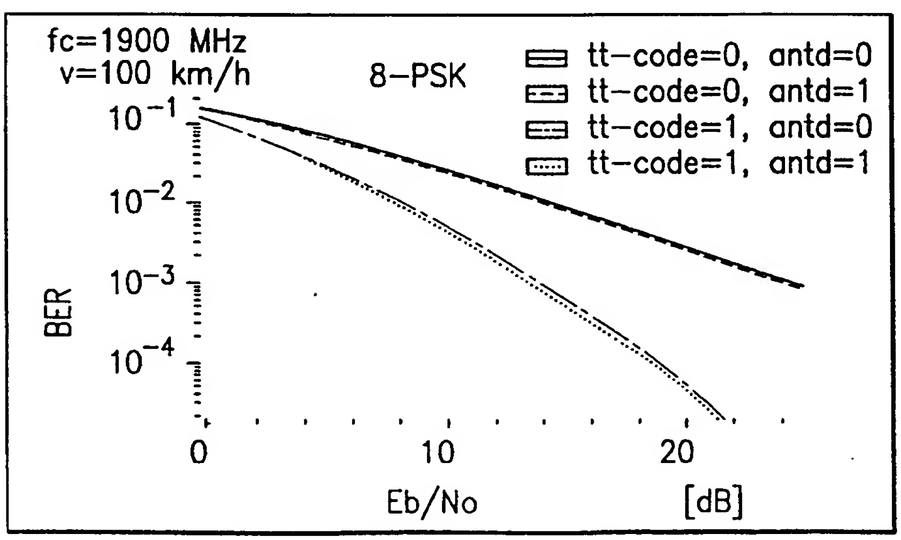

FIG.12F

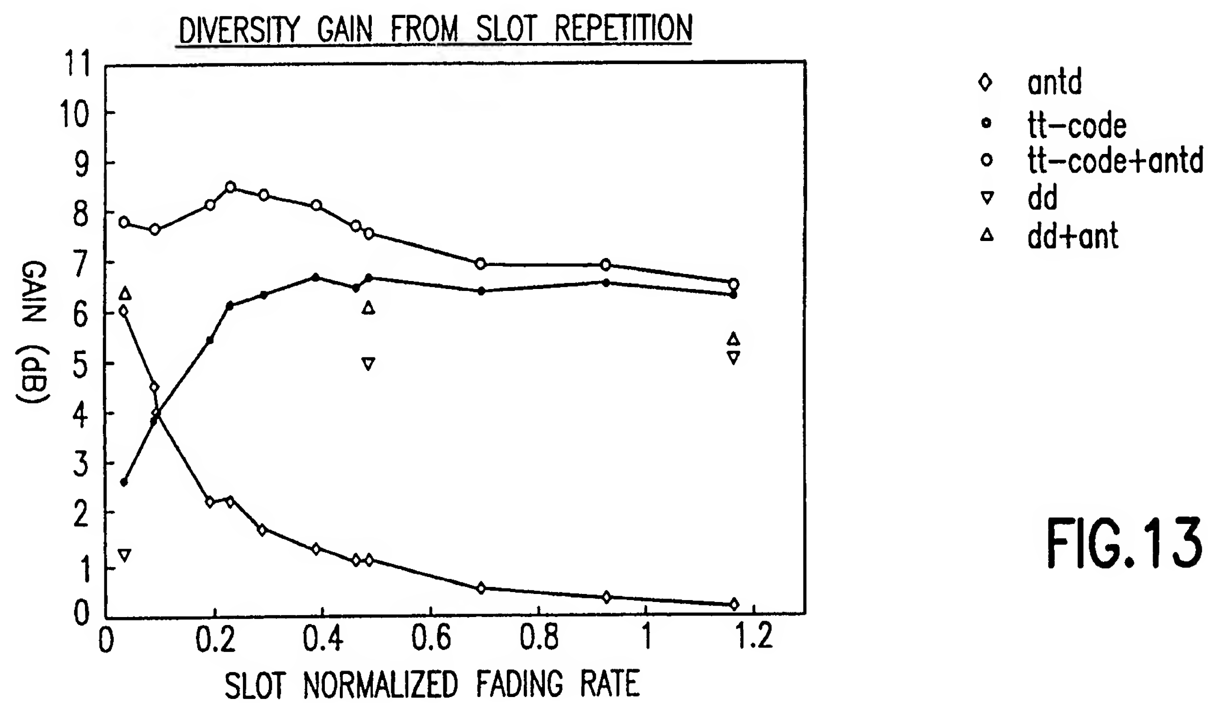

FIG.13

14	35	3	33	3	33	3	33	3	2
SYNC	DATA	PILOT-1	DATA	PILOT-2	DATA	PILOT-3	DATA	PILOT-4	RAMP

PROPOSED SLOT FORMAT (ALL NUMBERS INDICATE SYMBOLS)

FIG.14

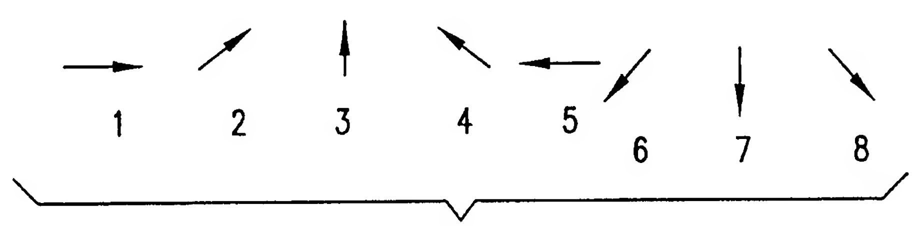

FIG.15

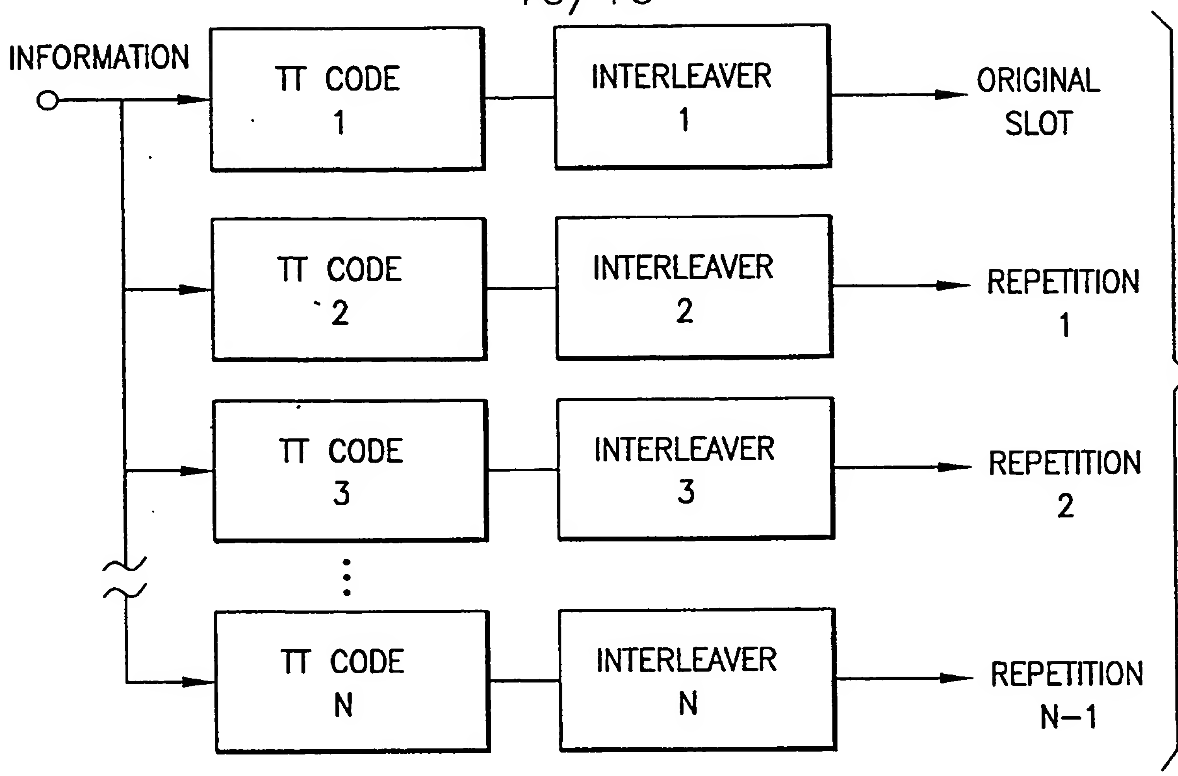

FIG.16

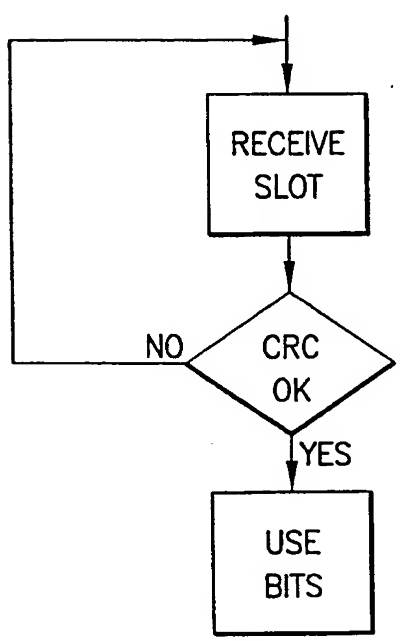

FIG.17

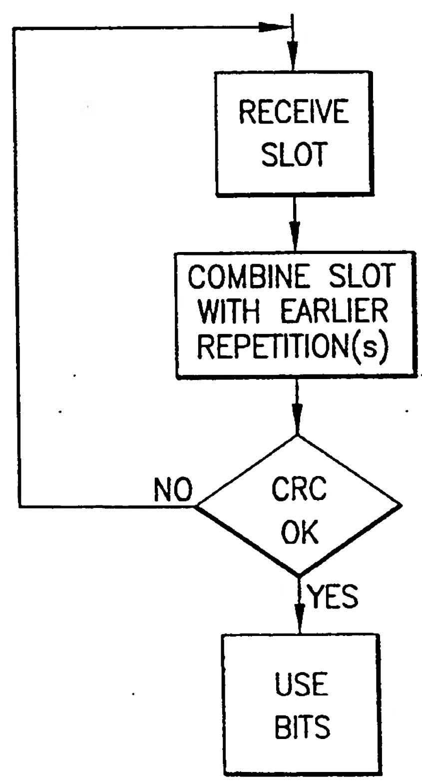

FIG.18